Hydrological and Ecological Survey of the Port Davey/Bathurst Harbour Estuary 1988-1989.

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Survey Summary

Five field trips were conducted to the Bathurst Harbour/Port Davey area between October 1988 and July 1989. During each trip the hydrology, benthic fauna, plankton and fish assemblages in the Bathurst Harbour estuary were surveyed.

During the winter period of peak freshwater outflow, a brackish surface layer (≈15 $^{o}/oo$) was present to a depth of ≈4 m throughout the estuary. The halocline broke down during summer with surface salinities of ≈29 $^{o}/oo$ prevailing. Bottom waters were close to fully marine (≈33$^{o}/oo$) throughout the year.

Surface waters in Bathurst Harbour were found to be extremely depleted in nitrates (<0.1 µM). Oxygen levels were also very low (≈35% saturation) during February but were near fu saturation during the other sampling periods.

Dinoflagellates and copepods were both extremely abundant in Bathurst Harbour. Diatoms were also abundant during the summer field trips, but were much less common than dinoflagellates on other occasions. Diatoms did, however, occur in higher densities than dinoflagellates in the waters of Port Davey. The plankton community (>20 µm mesh size) in Bathurst Harbour was dominated by few taxa, particularly during the winter months. The dinoflagellate *Dinophysis acuminata* provided >99% of phytoplankton numbers in October 1988 and July 1989, while the copepods *Gladioferens inermis* and *Oithona australis* and the appendicularian *Oikopleura* sp. provided almost all of the zooplankton numbers.

The diversity of benthic plants and animals decreased rapidly up the Bathurst Harbour estuary. Discrete communities of benthic organisms, both sessile and motile, were found at the western entrance to Bathurst Channel and in the rest of the estuary. The overlap zone between the different communities was a relatively small area between Sarah Island and Schooner Cove.

Mobile invertebrates were most abundant at the Bathurst Channel and Port Davey sites in February, and at the Bathurst Harbour sites in December. They showed high fidelity to location, with little indication in this study of a migration up or down the estuary in response to changes in salinity. Very few mobile invertebrates were found in Bathurst Harbour below 4 m depth.

Fishes in the Bathurst Harbour estuary also showed little response to seasonal changes in salinity. A number of fishes were , however, possibly prevented from entering the estuary during February because of low oxygen concentrations then prevailing.

The assemblage of Bathurst Harbour fishes collected by gillnet was unusual in being dominated by sharks and skates, with all of the common species also being distributed in water depths >50 m along the continental shelf. The assemblage thus has many characteristics typical of a deep water assemblage. Included amongst the Bathurst Harbour fishes was a previously unknown species of skate which may be restricted to the estuary.

By far the most common of the larger fishes was the white-spotted dogfish *Squalus acanthias*; this species comprised 86% of the total gillnet catch. Despite these large catches, a tagging study in which a very high proportion (26 %) of tagged dogfish were recaptured indicated that the total population in the estuary was not huge, being in the order of only 2,500 animals. Tagged animals roamed widely through the estuary.

The major recommendations of the study are that gillnets be banned from the Bathurst Harbour estuary, that the low nutrient status of the estuary be maintained, and that steps be taken to ensure that the unique *Caulerpa* algal beds in Kelly Basin be preserved.

Chapter 1: **General Introduction**

A single large sheltered inlet, Port Davey, is present along the 250 km section of Tasmanian coast between Macquarie Harbour on the western coast and Recherche Bay on the southeastern coast. This coastal embayment was formed by a marine transgression into the lower reaches of the Davey River, the largest river to empty into the sea on the southwestern coast of Tasmania. Port Davey thus represents a major corridor for freshwater transport to the sea, with a number of other large river systems also flowing into the embayment via Bathurst Channel, a complex inlet on Port Davey's eastern margin.

Bathurst Channel is a heavily indented channel, approximately 1 km wide, which traverses for 12 km through quartzitic hills (see fig. 2.1). It superficially resembles a fjord, and was initially considered to be one, however it is now recognized to be a drowned river valley of the trellis type (Baker & Ahmad 1959). Hydrographic charts of the area (Australian Admiralty Charts AUS 175 and AUS 176) surveyed in 1922 indicate that the bottom of Bathurst Channel varies from 15 m - 40 m depth, but that a relatively shallow sill (≈13 m) at its western end separates the channel from the deeper waters of Port Davey and the open sea. At its eastern end, Bathurst Channel forms the sole outlet for Bathurst Harbour. Two large river systems, the Old and the North Rivers, empty into Bathurst Harbour, while a third, the Spring River, enters Bathurst Channel directly.

Bathurst Harbour consists of a large (≈7 km long, ≈5 km wide) basin, surrounded on all sides by hills. The floor of Bathurst Harbour is flat, rising gradually from ≈7 m deep in the eastern sector to slightly shallower depths (≈6 m) near its western outlet (Australian Admiralty Chart AUS 176). The area was probably once a large buttongrass plain which became inundated by marine water following recent sea level rises.

Even if nothing was known of the physical or biological characteristics of Port Davey or Bathurst Harbour, this estuarine system could be described unequivocally as unique because it is the only large estuary in southern Australia without road access, without any of the rivers draining into it being constrained by weirs or impoundments, or without significant human impact (except perhaps for landscape modification due to increased fire frequency). Apart from two small tin leases operated beside Moth Creek near Melaleuca Inlet, no development occurs within the Port Davey catchment area. The permanent population of the area consists of three tin miners, with a transient population of fishermen, bushwalkers, sailors and airborn tourists reaching a daily maximum of ≈100 during summer.

For the same reason that the embayment is unique, namely its isolation, it is also the least known large estuary in southern Australia. Until 1984, the only information on the estuarine and marine biota of the area was anecdotal information on occasional fishes, molluscs and crustaceans sighted in the region (e.g. Scott, 1875; Lord, 1927; Davis, 1955), an inventory of 19 species of mollusc compiled by John Thomson (1978a), and a short unpublished report by the University of Tasmania Biological Society (McIntosh, 1969) listing several fish and copepod species. In 1984 a report describing fishes and benthic plants and animals of the area, and its potential as a marine reserve, was published (Edgar, 1984a). Last (1983) also included some locality data for beach-seined fishes in the area in his doctoral thesis.

In order to partly remedy the lack of information on the Bathurst Harbour/Port Davey marine and estuarine ecosystem, the Department of Lands, Parks and Wildlife initiated the present survey with the aim of quantifying the seasonal changes in the more important hydrological and biological features. The study has also attempted to deduce the major ecological processes which occur there. Such information is particularly important for optimal management of the region - to allow assessment of the impact of possible future developments. The recreational demands on the area are increasing and will inevitably continue to escalate as the value of this World Heritage Area wilderness becomes more recognized. If any development does occur, the data provided by this investigation should have considerable value in providing a baseline against which any future changes can be compared. On a scientific level, the study provides unique information for southern Australia on the natural, pre-disturbance state of a large estuary.

The study has been concentrated on the Bathurst Harbour/Bathurst Channel region rather than Port Davey itself because the Bathurst Harbour/Bathurst Channel estuary (henceforth referred to throughout this report as the Bathurst Harbour estuary) has the most unique physiographic character, with a great diversity of geomorphological features. It also has restricted water circulation; consequently it is clearly important to have some idea of water movement and residence times to make approximate predictions of the fate of any introduced pollutants. Bathurst Harbour and associated Melaleuca Inlet and Lagoon also would be most affected by future human impact because the tin mine, an airstrip and bushwalking facilities are all located in this area.

Chapter 2: Hydrology

Introduction

Because of its isolation, nothing was known of the hydrology of Port Davey or the Bathurst Harbour Estuary, other than that the surface waters were highly stained by tannins and that the freshwater entering the system had an ionic composition similar to seawater (Buckney & Tyler 1973), until the Tasmanian Government commissioned a survey of the resources of South West Tasmania in 1977. As part of this South West Tasmania Resources Survey, two hydrological surveys were conducted in the region, the first between 31 December 1977 and 6 January 1978 (Thomson 1978a) and the second from 16 to 20 July 1978 (Thomson 1978b). During both surveys, water temperature, salinity, pH and dissolved oxygen concentrations were measured at one to three depths at a number of stations in Kelly Basin, Port Davey, Bathurst Channel, Bathurst Harbour and Melaleuca Inlet. No further hydrological surveys were undertaken from that time until the present.

Thomson (1978a,b) found during his surveys that Port Davey and Bathurst Harbour were more marine than previously anticipated. Bathurst Harbour and Bathurst Channel were highly stratified with a brackish layer overlying marine waters. The brackish layer was found to extend to a depth of 4 m in winter but to only 2 m in summer.

The present investigation was aimed at extending Thomson's results. Data obtained during this study should encompass normal seasonal extremes in hydrology within the Bathurst Harbour estuary; one survey (8 October 1988) was conducted during a month of exceptionally high rainfall, the wettest month on record at Melaleuca, while another (8 February 1989) was conducted during the middle of a dry summer (D. King, meteorological records).

Methods

Hydrological data were collected on five occasions between 8 October 1988 and 25 July 1989 at ten stations along a transect running from the mouth of the Old River in Bathurst Harbour to the western side of Breaksea Island in Port Davey, and at five stations along a transect running along Melaleuca Inlet from the Boat Landing in Melaleuca Lagoon to Celery Top Island (fig. 2.1). Additional hydrological data were collected from three sites along the Old River (First Bend, Old River Tasmap grid reference 374024; Huon Pines, 378032; Islet, 386037) on 27 November 1988 and 25 July 1989, and four sites on the Davey River (Carvers Point Shoal, Port Davey Tasmap grid reference 130135; Settlement Point, 118150; Foot Track Islet, 122204;

Davey Gorge, 132212) on 12 February 1989. At each station salinities and water temperatures were recorded using a Hamon Salinometer at 1 m intervals for the first 10 m below the water surface and then 2 m intervals to the bottom. Water samples were also collected for nitrate analysis at Stations 1 (Old River Mouth), 3 (Bathurst Harbour 2), 5 (Platypus Point), 6 (Farrell Point), 8 (Sarah Island) and 9 (Breaksea Island East). At these stations a Niskin bottle was triggered at depths of 0 m, 2 m and 0.5 m above the bottom, and at 4 m and 6 m if water depths allowed. The sample was then retrieved and preserved using $HgCl_2$ for analysis of NO_2^- and NO_2^-+NO_3^- in the laboratory using a Technicon AutoAnalyser (Dept of the Environment). Water samples were also collected at various depths from Stations 3, 5, 6 and 8 for oxygen and salinity analysis using the laboratory methods of Major *et al.* (1972). Oxygen samples were transferred from the Niskin to a BOD bottle on the boat, fixed immediately by the addition of $MnSO_4$, KI and H_2SO_4, and stored in the dark. The laboratory salinity measurements were used to calibrate the *in situ* salinity data.

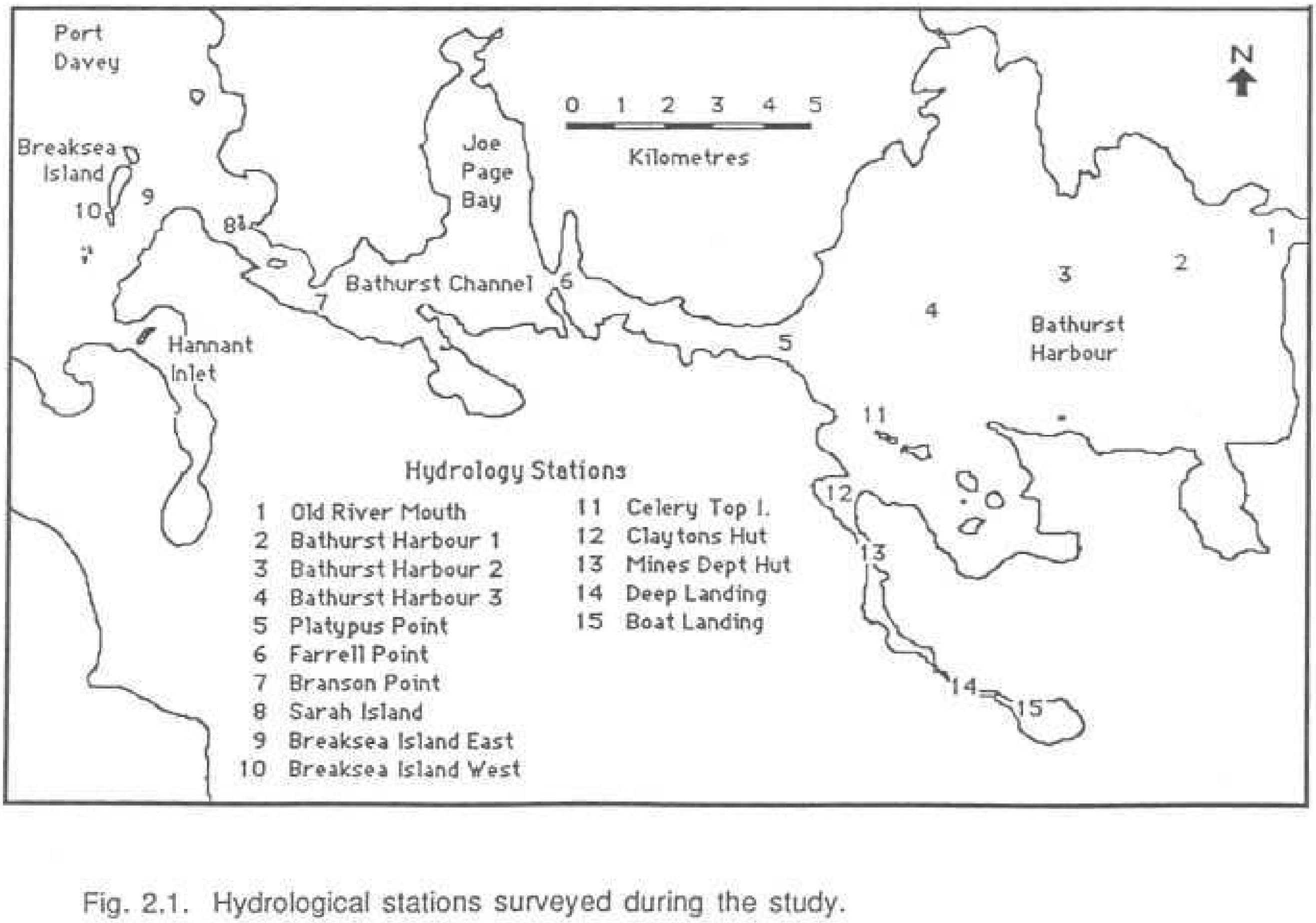


Fig. 2.1. Hydrological stations surveyed during the study.

Measurements of water transparency were made on 27 November 1988, 8 February 1989, 27 May 1989 and 25 July 1989 by lowering a 230 mm diameter plankton net vertically in the water column and recording the maximum depth at which it could be observed from the surface.

Results

Water temperature profiles along the Bathurst Harbour/Bathurst Channel transect are shown in fig 2.2. Water temperatures varied more in Bathurst Harbour than at the western outlet of Bathurst Channel, presumably because of the large expanse of shallow water in Bathurst Harbour, the highly variable riverine input, and the buffering provided by seawater near the outlet.

Waters below 5 m depth maintained a relatively constant temperature throughout the year, varying only between 12 and 14 °C during the spring, autumn and winter sampling trips, and increasing slightly to ≈17 °C during summer. Maximum-minimum thermometers did, however, indicate that the annual temperature range (≈10-19 °C) for water at 8 m depth (table 2.1) was greater than would be expected from the survey data.

Table 2.1. Temperature range (°C) recorded by maximum-minimum thermometers placed at 1m and 8 m depths at two sites, Sarah Island and Celery Top Island, between 27 November 1988 and 27 July 1989.

Depth (m)	Sarah Island	Celery Top Island
1	9.0-20.2	5.1-23.1
8	11.1-18.9	9.0-19.8

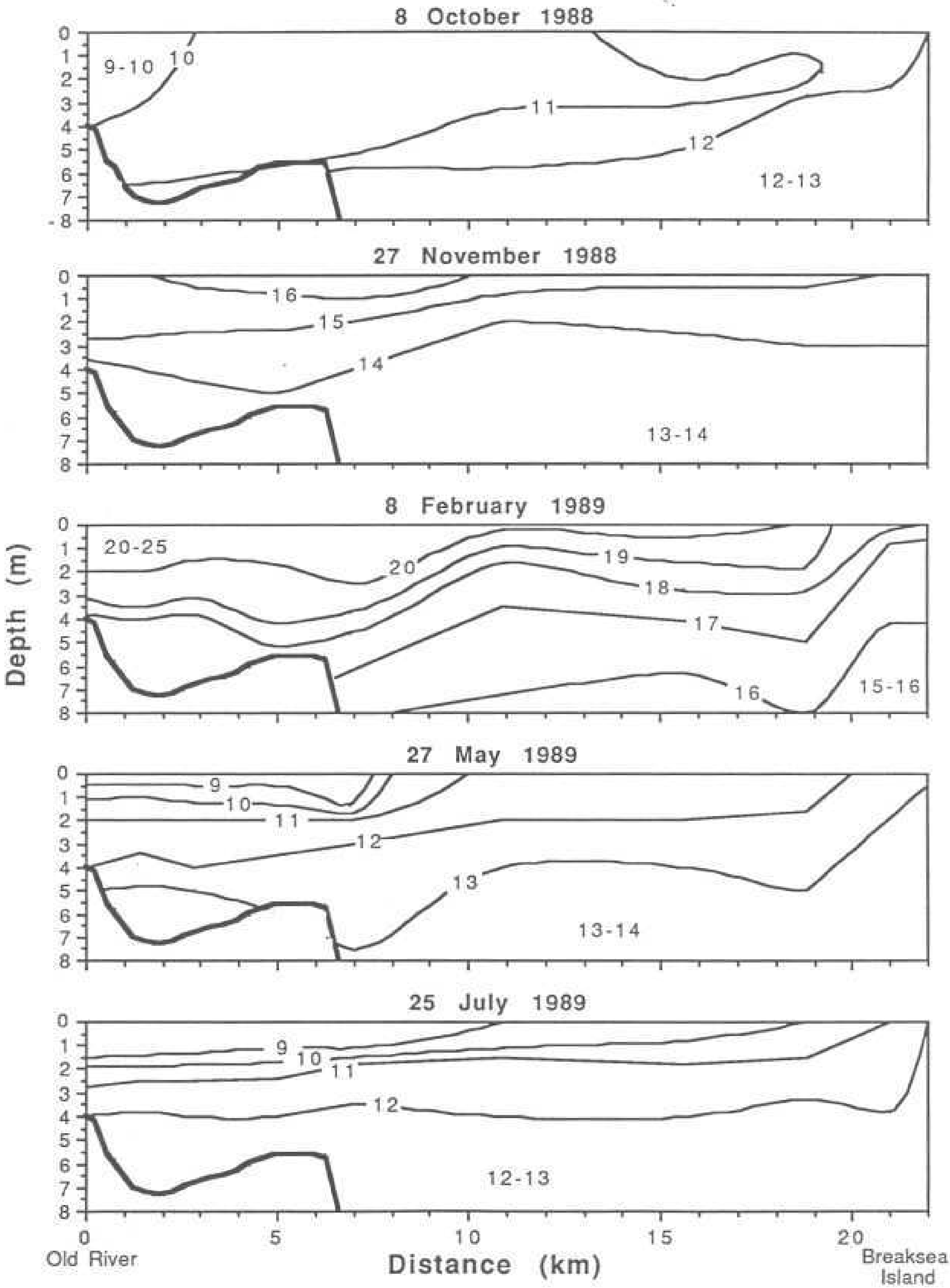


Fig. 2.2. Temperature profiles (°C) from the mouth of the Old River to Breaksea Island as recorded during the various field trips. Bathurst Harbour seabed is shown by bold line.

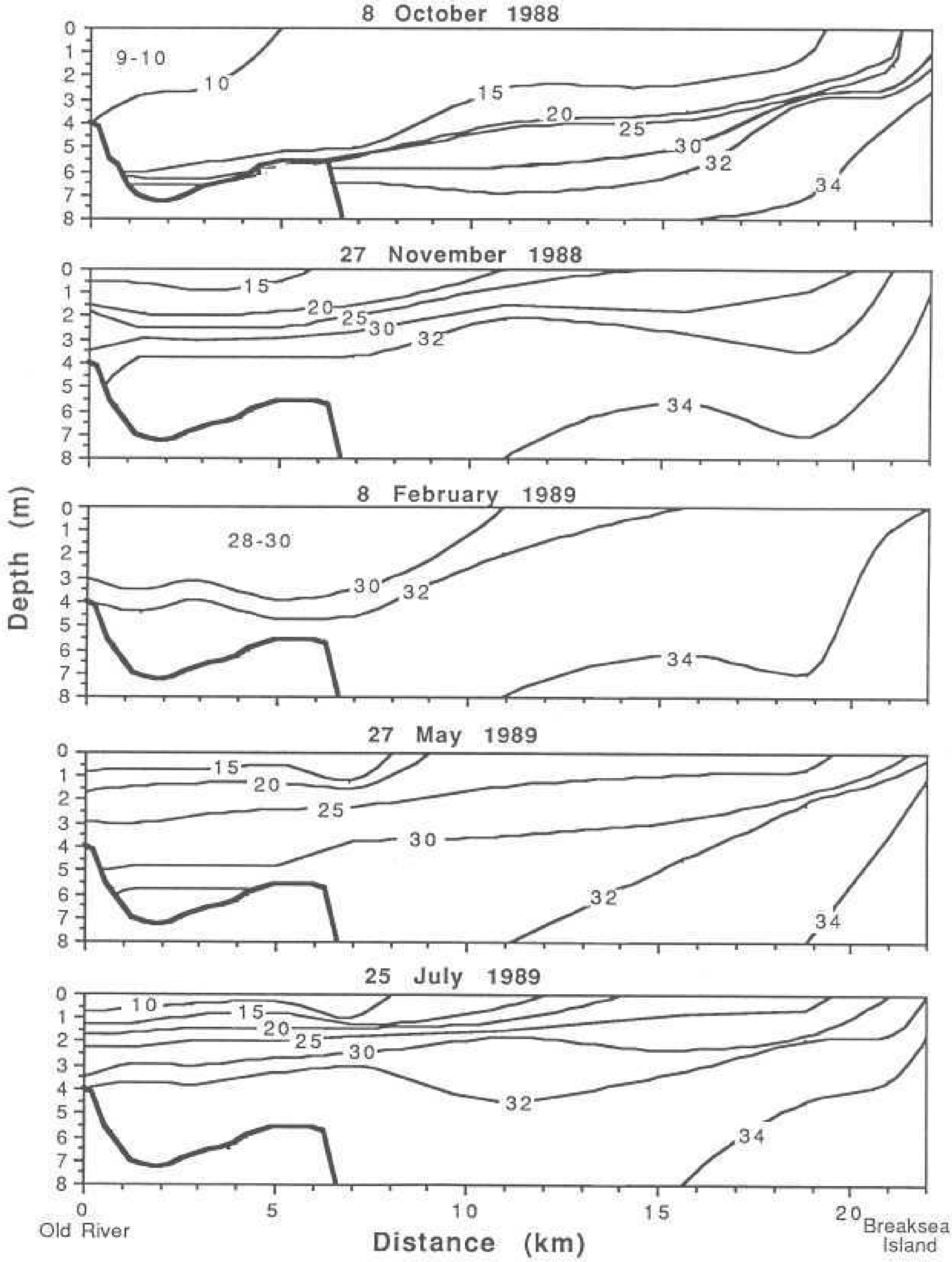


Fig. 2.3. Salinity profiles (°/oo) from the mouth of the Old River to Breaksea Island as recorded during the various field trips. Bathurst Harbour seabed is shown by bold line.

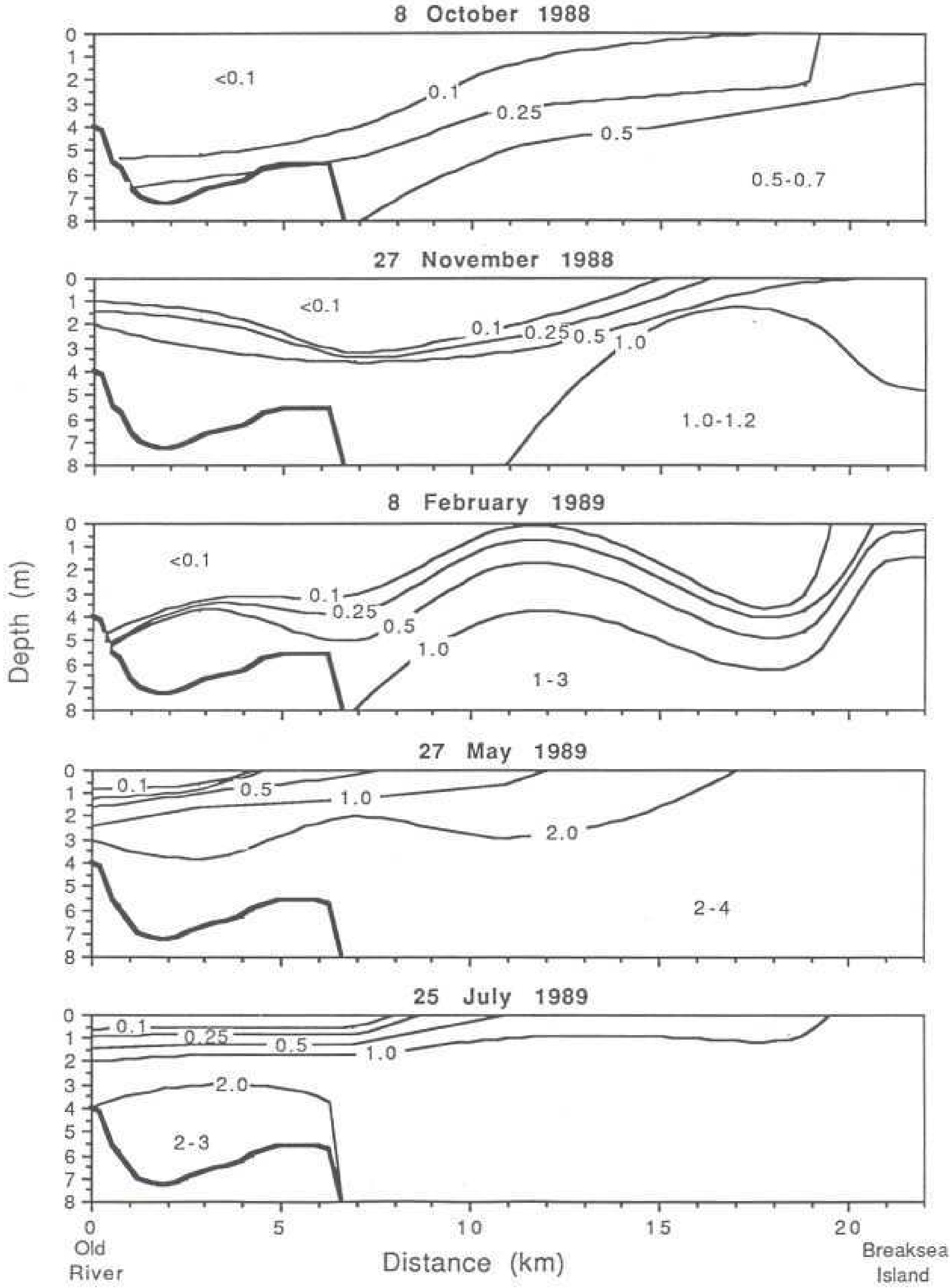


Fig. 2.4. Nitrate concentration profiles (μM) from the mouth of the Old River to Breaksea Island as recorded during the various field trips. Bathurst Harbour seabed is shown by bold line.

Rapid temporal and spatial changes in water temperatures occurred in the surface 4 m. During the summer months, surface water temperatures were several degrees warmer than bottom waters, while the thermocline was overturned and the reverse situation prevailed during winter. In October 1988 there was little temperature difference between the surface and the bottom.

On most sampling occasions, a well-defined halocline was present in the top 6 m, gradually decreasing in depth from Bathurst Harbour to the western outlet of Bathurst Channel and ceasing to exist outside Breaksea Island (fig. 2.3; appendix 2). The halocline disappeared during February, a period when only slightly-diluted marine waters occupied Bathurst Harbour. Surface salinities in Bathurst Harbour nevertheless varied surprisingly little during the sampling trips throughout the rest of the year, ranging from only 7 to 15 °/oo. Freshwater input into Bathurst Harbour outside the summer months primarily acted to depress the level of the halocline and extend the distance that the brackish layer descended down the estuary, rather than dramatically reduce surface salinities. During the period of peak freshwater outflow in October 1988, the wettest month ever recorded at Melaleuca (D. King, meteorological records), the halocline was depressed to 6.5 m depth in Bathurst Harbour, while in other months of the year marine (>30°/oo) water extended to within ≈3 m of the surface. The surface waters of Port Davey between Bathurst Channel and Breaksea Island were brackish during the October survey. Fully-marine (>34 °/oo) water maintained a relatively constant depth gradient on all sampling occasions, occurring at a depth of ≈5 m at Sarah Island and gradually sinking along the channel to a depth of ≈14 m at Platypus Point.

On three sampling occasions bottom salinities in the eastern and central sectors of Bathurst Harbour were higher than at corresponding depths near Platypus Point in Bathurst Channel (on 27 November, 27 May and 25 July salinities were 34.7 °/oo, 33.0 °/oo and 34[illegible] °/oo at 7 m at Bathurst Harbour 1 but only 32.9 °/oo, 31.5 °/oo and 33.2 °/oo at 10 m at Platypus Point, respectively). Bottom water in Bathurst Harbour was also markedly reduced below marine salinities (27.5°/oo) on 9 October 1988. The bottom water in Bathurst Harbour was clearly isolated from the marine water of Bathurst Channel for much of the year, gradually diluting during these periods of isolation by the diffusion and convection of brackish water. Dense intruding marine water replenishes Bathurst Harbour bottom water whenever the halocline at the eastern end of Bathurst Channel approaches close to the surface. Such intrusions of marine water occurred on at least three occasions during the study period: between 9 October and 27 November 1988, during February, and between 27 May and 25 July 1989.

The bottom water in the deeper sections of Melaleuca Inlet was also isolated from Bathurst Harbour by the shallow banks near Claytons Hut for much of the year. On all sampling occasions bottom salinities were higher in the deep channel near the Mines Hut than downstream at Claytons Hut, while on the 12 October, during peak freshwater outflow, salinities were higher at the Melaleuca Boat Landing at 3 m depth than at the same depth in Bathurst Harbour at Celery Top Island. During February water throughout Melaleuca Inlet was quite saline (>25 $^{o}/oo$), with no indication of a halocline such as was observed during the other surveys.

Brackish water, and perhaps marine water in summer, enters the Old River as far as the first riffle bank (2 km upstream), but is flushed from the shallow (<1 m) sections of the river during periods of heavy rain (appendix 2). During summer, the only period sampled, marine bottom water was present all the way up the Davey River to the downstream end of the Davey Gorge (appendix 3).

Nitrate concentrations were extremely low in Bathurst Channel and Bathurst Harbour (fig. 2.4); nitrates were in fact undetectable (<0.1μM) in the surface waters at the eastern end of Bathurst Harbour throughout the study. The Old River apparently provided little nitrate input into Bathurst Harbour; a surface concentration of only 0.6 μM was recorded 1 km up the Old River at the Huon Pines on 25 July 1989.

Nitrate levels increased with depth at all sites, with a maximum recorded concentration of 3.9 μM at 6 m at the Bathurst Harbour 1 station in May. Nitrate concentrations also generally increased towards Port Davey, apart from May and July 1989 when there was a slight reverse trend in waters >4 m depth.

Unusually high nitrate levels were recorded at Farrell Point in summer (fig. 2.4), indicating that a slight upwelling of nutrient-rich bottom water may occur in this area of rapid tidal current flow. The temperature and salinity profiles for all sampling occasions other than October provide further indications of a Farrell Point upwelling, with a corresponding downwelling near Platypus Point.

During the cooler months, dissolved oxygen concentrations were high throughout the Bathurst Harbour estuary (Table 2.2). However at the time of the February survey, oxygen concentrations were extremely low at all stations sampled (<110 μM = 46% saturation), except for surface waters near the Old River Mouth (171 μM = 74% saturation). The lowest recorded oxygen saturation level was at 20 m depth at Sarah Island (23% saturation). Low dissolved oxygen levels were also recorded in November at 4 m depth at Old River Mouth (107 μM) and at 40 m depth at Sarah Island (91 μM).

Table 2.2. Seasonal oxygen determinations (µM) at Old River Mouth (Station 1), Bathurst Harbour (Station 2), Platypus Point (Station 3) and Sarah Island (Station 5).
* An oxygen concentration of 90µM was recorded at the surface at Station 5 during November; this result is inconsistent with the others and is probably spurious.

Depth (m)	8 October 1988			27 November 1988				8 February 1989				27 May 1989			
	Station			Station				Station				Station			
	1	2	3	1	2	3	5	1	2	3	5	1	2	3	5
0	285	286	275	250	251	200	*	171			63	266	268	258	250
2	291			243								248	253	238	252
4	286	274	260	107	236	237	251	106	73		72		242		252
6					233					71			234	230	
7		236							102						
10						232					75			232	
15			258							78	68				
20											60				
25											72				251
40							91								

Because of the extremely high tannin content of the freshwater entering the Bathurst Harbour estuary, light penetration through the surface water of Bathurst Harbour was extremely poor outside the February survey (fig. 2.5). The water was, however, extremely clear below the halocline in all months (personal observations). Similar water transparency profiles were recorded for May and July 1989.

Discussion

The data collected on 27 November 1988 and 25 July 1989 differed only slightly from Thomson's (1978a,b) data collected on 31 December 1977 and 20 July 1978, respectively. The two minor ways in which Thomson's surveys differed from the more recent ones in the same seasons were that more freshwater was present during the early surveys, and the bottom water in Bathurst Channel on 20 July 1978 was 1 °C cooler than on 25 July 1989. This difference in winter water temperatures possibly reflects a slight seasonal difference in the date on which water temperatures were recorded; the temperature of 11.5 °C at Hixson Point on 20 July 1978 (Thomson, 1978b) is above the 11.1 °C minimum temperature recorded at 8 m depth at nearby Sarah Island (Table 2.1). A more likely explanation for the temperature difference between

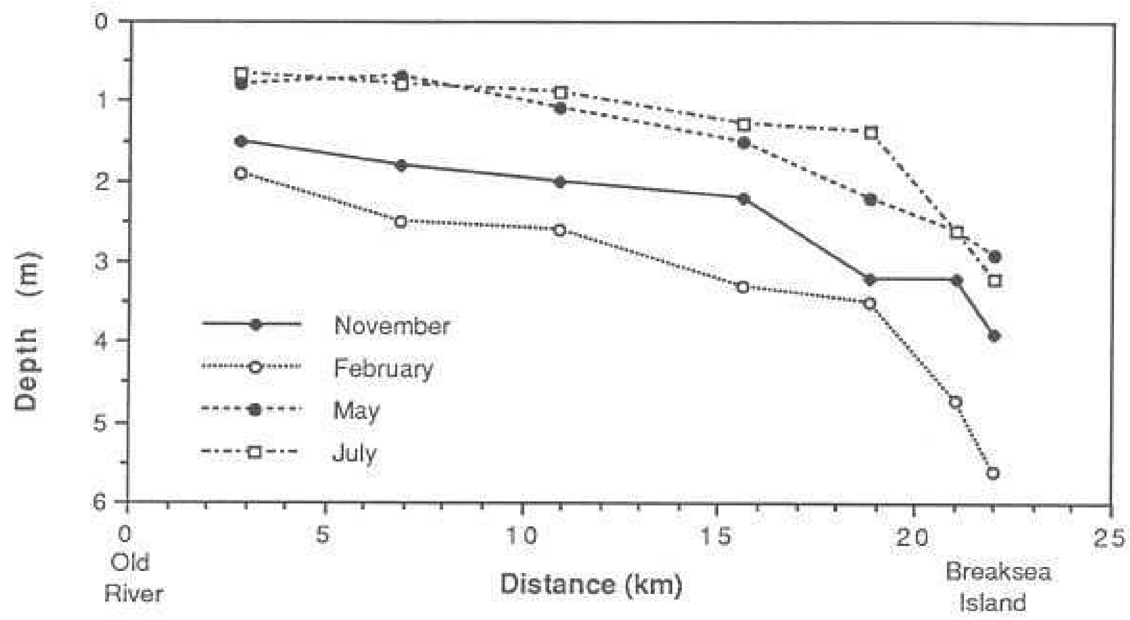


Fig. 2.5. Water transparency along the Bathurst Harbour estuary from Old River Mouth to Breaksea Island.

years is that it reflects a real interannual difference in oceanic water temperatures off southern Tasmania; Harris *et al.* (1987) indicated that oceanic water temperatures off Tasmania were unusually low in 1978.

Although Thomson's 31 December 1977 data were referred to by him as summer data, it is now clear from the 8 February 1989 survey that the summer hydrology of Bathurst Harbour estuary differs markedly from the hydrological regime prevailing during the rest of the year, including the period described by Thomson (1978a). This difference between seasons resulted in, for example, Thomson (1978a,b) not detecting any major reduction in dissolved oxygen during his survey whereas oxygen concentrations were low at sites examined throughout the estuary in February 1989. The major hydrological features of the Bathurst Harbour estuary in summer are that (i) marine waters penetrate with little dilution throughout the estuary, except in waters immediately adjacent to rivers and creeks, (ii) a strong thermocline exists near the surface, (iii) considerable light penetrates below 7 m, the depth of the floor of Bathurst Harbour, and (iv) oxygen saturation levels are low, well below the minimum level required for the long-term survival of many marine animals. In this context it should be noted that oxygen levels in mid-summer need to be re-surveyed because some inaccuracy may have been introduced into the 1989 determinations due to the lengthy period of time (3 weeks) between the collection and laboratory analysis of samples. Samples collected on other surveys were subjected to a similar 3 week time delay between collection and analysis, however they were stored at lower temperatures. It is nevertheless unlikely that oxygen concentration levels would have been grossly (>20%) inaccurate because surface samples collected on the same summer day as other samples from near the mouth of the Old River showed relatively high oxygen saturation levels. Water flowing out of the Old River was presumably near full saturation, hence surface samples collected at this station would be expected to be higher than at other sites.

Only one other estuary in Australia, Macquarie Harbour in western Tasmania, has physical and hydrological characteristics which are at all comparable with Bathurst Harbour. The Macquarie Harbour and Bathurst Harbour estuaries are unique in Australia in having both (i) highly stratified waters, with a darkly-stained brackish surface layer, and (ii) relatively deep (>30 m) basins, occupied by saline water, which are separated from the open sea by shallower areas. The results of hydrological surveys conducted in Macquarie Harbour during 1985 (Cresswell *et al.* 1989) nevertheless indicate a considerable number of differences between the two systems.

Cresswell *et al.* (1989) considered Macquarie Harbour to be a three-layer system with a surface layer of mixed marine and freshwater origin, a marine bottom layer and an intermediate slowly-changing mid-layer. The marine bottom layer in Macquarie Harbour is considerably less saline (30-31 ^{o}/oo) than the bottom layer in Bathurst Channel (34-35 ^{o}/oo), indicating that marine water flow into Bathurst Channel is much less restricted than into the other large estuary. My surveys also provide no indication of a mid-layer in Bathurst Channel, although it is possible that such a layer exists but was not recognized because of the very limited number of nitrate and oxygen samples collected; Cresswell *et al* . (1989) largely inferred the existence of a mid-layer at Macquarie Harbour from oxygen and nitrate data. The oxygen and nitrate data from Bathurst Channel are nevertheless sufficient to show that there is little similarity in the profiles of these parameters between the two estuaries.

The lowest levels of dissolved oygen at Macquarie Harbour are shown in figures 2 and 3 of Cresswell *et al.* (1989) to be ≈100 µM at ≈20 m depth, with little change between the four surveys. By comparison, dissolved oxygen was <50µM at all depths at Sarah Island, Bathurst Channel, on 8 February 1989. Thus, oxygen shows much greater seasonal variation at Bathurst Harbour than at Macquarie Harbour, with extremely low values occurring during summer. This difference between estuaries is probably extremely important to the biota, restricting many marine animals from penetrating into Bathurst Harbour during periods of low oxygen saturation.

Nitrate levels were generally much lower at Bathurst Harbour than Macquarie Harbour, ranging from <0.1 to 3.9 µM at Bathurst Harbour but generally falling between 20 and 150 µg/l (i.e. 1.4 to 10 µM) at Macquarie Harbour (Cresswell *et al* . 1989). One hypothesis which explains the elevated nitrate levels at Macquarie Harbour is that there is a large nutrient input from the towns of Queenstown and Strahan; however, a more important source of nutrients is probably the freshwater entering Macquarie Harbour from the Gordon River. Most of this water has been discharged from the deeper sections of the Serpentine Impoundment, and consequently has a high nutrient load. Cresswell *et al.* (1989) indicate that the concentration of nitrate in Gordon River water entering Macquarie Harbour is ≈100 µg/l (≈7 µM), an order of magnitude higher than the level of ≈0.5 µM for water from the Old River entering Bathurst Harbour.

The surface nitrate levels at Bathurst Harbour are amongst the lowest for any estuary which has been investigated. While it is possible that the chemocline in Bathurst Harbour overturns for short periods, such as occurs in Port Hacking, N.S.W. (Rainer & Griffiths 1980), an estuary in which surface nitrate levels fall below 0.1µM in all seasons of the year is extremely unusual; I could find no reference to another estuary with this condition. A low nutrient estuary such as this could presumably only occur when several factors combine: (i) little nutrient input into streams within the catchment area because of inert surrounding rocks, (ii) no anthropogenic sources of nutrients such as fertilizers, sewage or the nutrient rich bottom waters of dams, (iii) a highly stratified system, with no major upwelling, and (iv) high densities of phytoplankton which rapidly absorb nutrients and ultimately cause them to be transported from surface waters to bottom sediments. This combination of factors, which is present in Bathurst Harbour, is possibly almost unique in the world.

Although no current or tidal data were collected during the investigation, the salinity data allow very rough estimates of water residence times in the system to be made. The residence time of water above the halocline in the Bathurst Harbour estuary is probably relatively low (<1 mo). Most of the brackish water present in Bathurst Harbour in early October had been flushed from the system by late November, and all of the brackish water present at that time had disappeared by February. The maximum residence time of surface water in Bathurst Harbour is clearly considerably less than 3 months. It is, however, possible that the residence time of water in the top 2 m is as low as 1 week. Bathurst Harbour has a semidiurnal tide with an atmospheric pressure component of equivalent magnitude to the lunar component. The tidal range is generally $\approx$0.3 m, although most of the water moving into Bathurst Channel during each tidal cycle is probably returned during the same cycle. Because of the greater freshwater throughput during winter, surface waters should have lower residence times in winter than in summer.

The saline water near the bottom of Bathurst Harbour was isolated from marine water in Bathurst Channel on four of the five survey periods, with replenishment (i.e. an increase in salinity) occurring on at least three occasions during the period of the study. The salinity profile in Bathurst Harbour was generally quite stable during the ten day periods in which field trips were carried out (personal observations), hence the bottom waters were probably isolated for considerable periods of time, possibly in the order of 3 months.

The fully marine (>34 ^{o}/oo) water in the deeper sections of Bathurst Channel maintained a stable profile during the study (fig. 3), hence nothing can be inferred about the residence time of this water, other than that it could be long.

Chapter 3: **Benthos**

Introduction

The benthic zonation patterns of prominent species at several sites in Port Davey and Bathurst Harbour were described in an early report on the biota of the region (Edgar 1984a). The most notable feature recorded in the previous study was the presence of a benthic faunal community rather than the normal plant community in shallow water at the western entrance to Bathurst Channel. Included in this community were a number of animal species which are normally restricted below 30 m depth and were present in water as shallow as 4 m. I suggested that the reason for sessile animals occurring in such shallow depths was that the darkly stained surface water prevented sufficient light penetrating below ≈4 m depth for the growth of plants, and thereby allowing animals which are normally outcompeted by plants to grow.

The zonation patterns of benthic plants and animals in the Bathurst Channel region were resurveyed using more accurate methods during the present study, with quantitative transects at a greater number of sites. The distribution and abundance of mobile invertebrate species, a group previously unexamined within the estuary, were also surveyed. This was done by placing artificial algal clumps, composed of tanikalon rope fibre, at defined depths at a number of sites, recollecting the artificial algae approximately two months later, and determining the abundances of the species present. This method was considered preferable to the more usual methods of collecting samples from natural habitats with grabs and suction devices because habitats change very rapidly within the Bathurst Harbour estuary, both horizontally and with depth, so it would have been impossible to distinguish whether a particular species occurred in a particular sample because of habitat requirements or because of the hydrological and physical environment. By maintaining a constant habitat for all samples, the effects of depth and distribution along the estuary could be separated, and any seasonal migration up and down the estuary or between different depths identified. Sample variation between artificial algal replicates is also very low; consequently, any future changes which occur within the estuary are much better monitored using this method to provide baseline data than by using methods which cannot be accurately repeated. The artificial algal clumps sample virtually all species of epifaunal invertebrates which live in the vicinity of the clumps (unpublished data from other sites). The method does not, however, sample infaunal species. Consequently, infaunal assemblages within the Bathurst Harbour estuary remain unstudied.

Methods

Benthic Flora and Fauna

The depth distribution of larger plants and sessile animals was surveyed between 10 and 15 February 1989 at eight sites in Bathurst Channel and Port Davey: Platypus Point, Farrell Point, Forrester Point, the point 500 m west of Forrester Point (referred to as W. Forrester Point), Turnbull Head, the east and west shores of Breaksea Island, and Shanks Island (fig. 3.1).

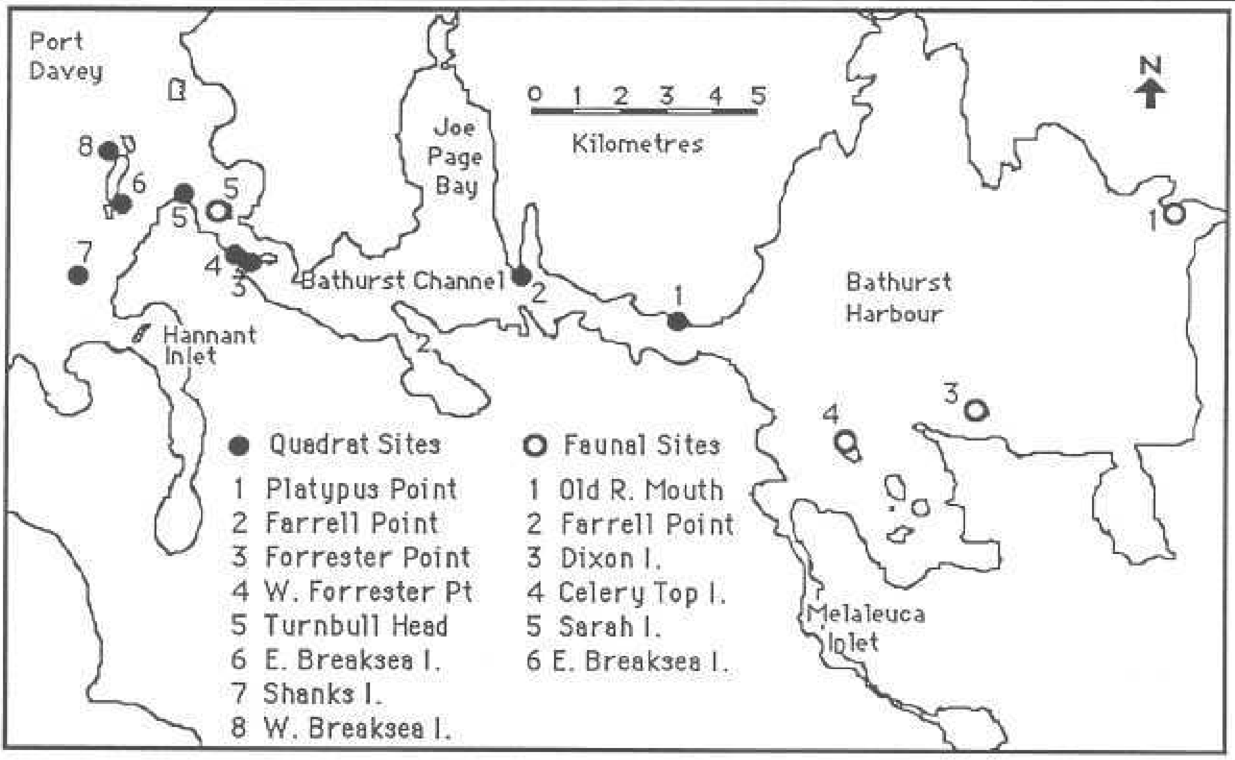


Fig. 3.1. Sites where benthic flora and fauna (quadrat sites) and mobile invertebrate fauna (faunal sites) were investigated.

At each site a 50 m measuring tape was placed along the seabed perpendicular to the shore from low water mark. At 2 m intervals for the first 10 m, and then at 5 m intervals to the end of the tape, a 0.5x0.5 m^2 quadrat was placed onto the substratum and the depth of the tape recorded using a depth gauge. From the quadrat, which was subdivided into 64 smaller sections, the percentage cover of each benthic species with >1% cover was estimated and recorded on an underwater notepad. Two transects were surveyed at each site.

Mobile Invertebrate Fauna

Mobile invertebrates were sampled using artificial algal clumps, consisting of 200 mm long strands of ≈1 mm width tanikalon rope fibre (≈50 g weight) tied together with nylon cord and attached by cord to the top surface of a brick. Replicate artificial algal clumps were placed at 1, 4 and 8 m depths off Celery Top Island, Farrell Point (Bathurst Narrows), Sarah Island and the east coast of Breaksea Island, at 1 and 4 m depths off Dixon Island, and at 1 m depth at the mouth of the Old River (fig. 3.1). After being submerged at the various sites for ≈2 months, the artificial algal clumps were individually enclosed underwater within plastic bags and the associated animals preserved by adding buffered formalin (≈5% v./v.). The invertebrates associated with each clump were extracted in the laboratory by pouring the the contents of each bag through a nested series of sieves ranging in size from 0.5 mm to 8 mm, and then counting the abundances of the species retained on each sieve. A more detailed explanation of the sampling protocol is given in Edgar (1990). Samples were collected at the various sites on 29 November 1988, 16 February 1989, 28 May 1989 and 27 July 1989, having been placed in the water on the preceding sampling date and on 10 October 1988. On three occasions (Sarah I. on 16 February; Dixon I. on 27 July; Breaksea I. on 27 July) single algal clumps were lost at the 1 m depth sites, presumably because of wave action. These samples consequently were not replicated.

Sites were classified using the log (x+1) abundance of the various invertebrate species at that site with all seasons combined. From these data a similarity matrix was calculated between pairs of sites using the Pearson correlation coefficient. The information in the similarity matrix was then heirarchically grouped using average linkage (Anderberg 1973) for presentation as a dendrogram. An inverse analysis which grouped the invertebrate species rather than the sites was also performed using the same data set and method.

Results and Discussion

Benthic Flora and Fauna

Bathurst Harbour:

Benthic macroalgae were not found below ≈2 m depth on reef habitats in Bathurst Harbour. The rock substratum was generally bare with a few patches of mussels (*Xenostrobus securis* and *Mytilus edulis*) below this level, with the red alga ?*Gracilaria* sp. occurring above. During the summer months *Cladophora* sp. and a filamentous red alga covered reefs in waters shallower than 1 m.

The occurrence of large algae such as *Carpoglossum confluens* at sites with considerable freshwater input in south-eastern Tasmania (e.g. the Huon River estuary) indicates that the osmotic effect of the freshwater in the brackish surface layer was probably not the reason for the lack of macroalgae in Bathurst Harbour. Macroalgae were more likely prevented from growing in the area because of the combination of lack of light in deeper waters (>2 m) and lack of nutrients near the surface. The kelp *Macrocystis pyrifera*, for example, requires ≈1 µM NO_3^- for normal growth (Gerard 1982). This concentration of nitrate is more than an order of magnitude higher than that recorded at the surface of Bathurst Harbour. It is therefore not surprising that *M. pyrifera* was not observed up the Bathurst Harbour estuary past Schooner Cove, near the western entrance of Bathurst Channel.

Sparse beds of the seagrass *Zostera muelleri* were present in shallow (<1 m), sheltered soft-bottom habitats in Bathurst Harbour. In deeper areas of the bay, the estuary floor consisted of very soft silts and muds. Samples taken using a dredge (1 cm mesh) from the bottom of Bathurst Harbour yielded extremely high numbers of the heart urchin *Echinocardium cordatum* but little else (a few polychaetes and a single helmet shell *Phalium semigranosum*).

The size-structure of *E. cordatum* was determined during each of the five field trips to the area by measuring the maximum length of ≈300 animals collected in a combined sample from the Harbour (fig. 3.2). This was done because the initial sample (on 10 October 1988) appeared to have two size frequency modes (at 15 and 25 mm test length); by following these modes through the year it was thought that the seasons of maximum and minimum growth could be determined. However contrary to expectation, the major size-frequency mode at 15 mm length did not change throughout the study (fig. 3.2). Either the growth rate of *Echinocardium cordatum* was extremely slow or animals within the population grew but suffered extremely high mortality on reaching ≈16 mm test length. Animals below 14 mm were not adequately sampled because of the dredge mesh size (10 mm). Hence, large numbers of small sized urchins were undoubtedly present in Bathurst Harbour but not collected.

The most surprising benthic species collected from Bathurst Harbour was the kelp *Ecklonia radiata*. A number of healthy-looking *E.radiata* plants were entangled in gillnets set for fish at the North Bathurst Harbour site (see fig. 5.1) and also a site 100 m west of Celery Top Island. Two hypotheses can be used to explain the presence of these plants. Either (i) the plants grew elsewhere, becoming detached from the substratum and transported to the sites in Bathurst

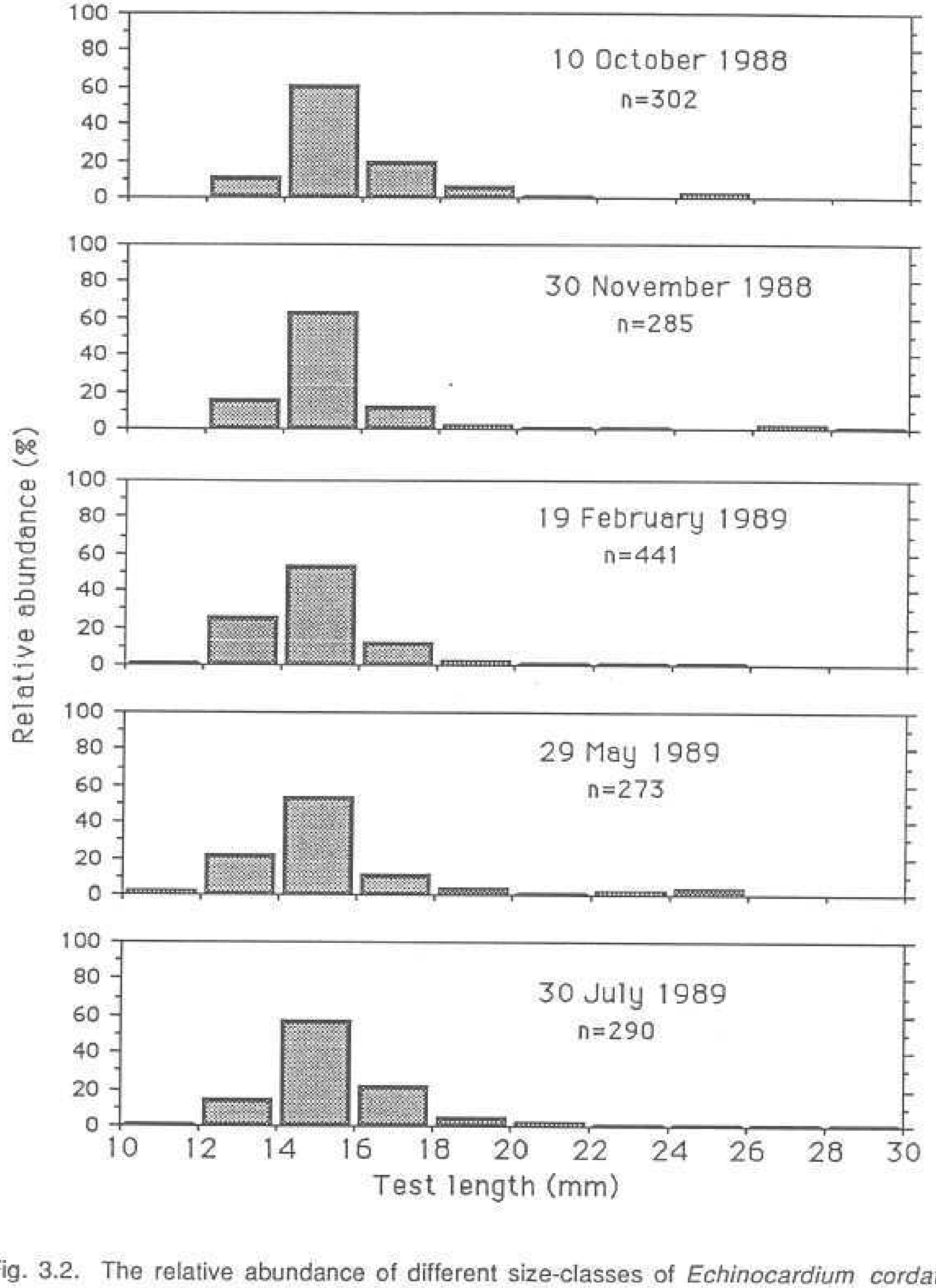


Fig. 3.2. The relative abundance of different size-classes of *Echinocardium cordatum* collected from Bathurst Harbour (n = number of animals measured in the sample).

Harbour by currents, or (ii) they grew *in situ*, receiving enough light despite their depth and sufficient nutrients because of their position below the chemocline. The first hypothesis is unlikely because currents in Bathurst Harbour are extremely weak. Currents certainly do not appear strong enough to drag the negatvely-buoyant plants up the incline from Bathurst Channel to Bathurst Harbour and then across several kilometres of mud bottom, with the plants maintaining a healthy appearance during this journey. The second hypothesis also does not seem overly convincing because of the extremely low light levels prevailing for most of the year and the apparent absence of sites for the attachment of the kelp holdfasts in the centre of Bathurst Harbour. This hypothesis is, however, more likely than the first because some rocky habitats may be present in Bathurst Harbour but were not observed during the study. Rocky substrata are shown on the Australian Admiralty Chart (AUS 176) to occasionally occur in Bathurst Harbour. *Ecklonia radiata* also probably has lower light requirements than other macroalgae in the region, surviving at greater depths than other large Tasmanian macroalgae (Edgar 1984b).

Bathurst Channel:

The distribution of the major benthic plants, as deduced during the quantitative survey, is shown in fig. 3.3. A discontinuity occurred in the benthos between Forrester Point and West Forrester Point, a distance of only 500 m. The discontinuity is clearly seen in fig. 3.4 where the maximum depth at which plants are abundant (i.e. they cover more than 10% of the reef) is plotted against distance down Bathurst Channel. It can also be readily observed in the field because over a very short distance the kelp-like alga *Durvillaea potatorum* ceases occurring in the lower intertidal zone and is replaced by *Hormosira banksii*. East of Forrester Point the flora showed similar characteristics to the flora of Bathurst Harbour, being dominated in the top 1m by *Hormosira banksii*, filamentous algae and occasional *Carpoglossum confluens*, and with almost no plants occurring below 2 m, other than a few bedraggled *Ecklonia radiata* plants which grew to 3 m depth.

The region between Forrester Point and Turnbull Head (the entrance to Bathurst Channel) is best considered as an overlap zone between the Bathurst Harbour and Port Davey ecosystems, although it also had a number of its own distinctive elements, with species such as *Ecklonia radiata*, *Macrocystis pyrifera* and *Zonaria* spp. being much more common here than elsewhere. The overlap area near Forrester Point was particularly rich in species, with an average of 22 plant and animal taxa observed during each transect, compared to an average of 9 taxa at the western entrance of Bathurst Channel and 15 taxa in transects off the west coast of Breaksea Island. The relatively high diversity of this assemblage was most apparent in shallow water (fig. 3.5). Moving away from Forrester Point towards the more exposed areas of Port Davey, the

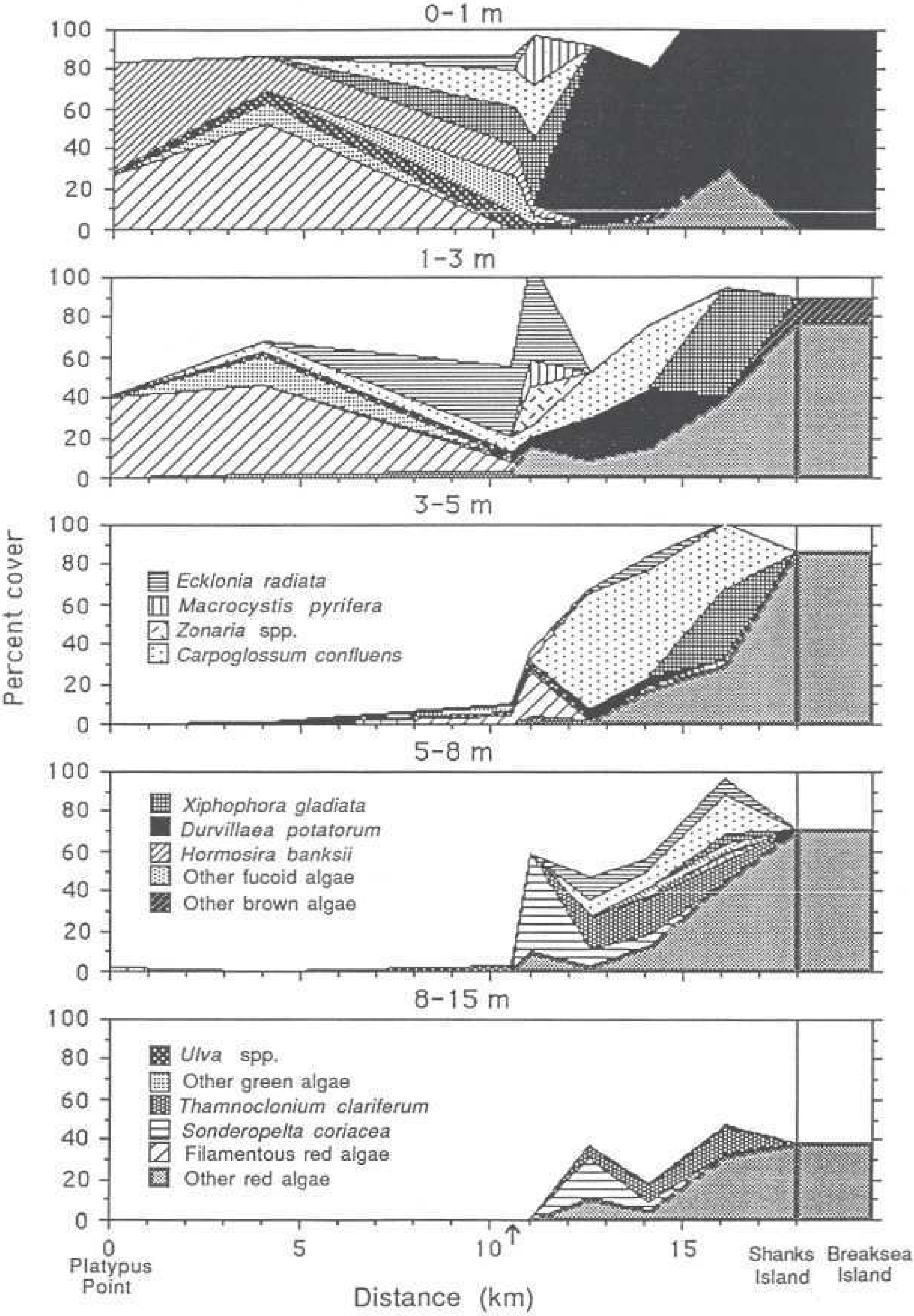


Fig. 3.3. The distribution of the major plant and animal groups at different depths between Platypus Point and Shanks Island, Port Davey. The last column shows the depth distribution of benthos off the western shore of Breaksea Island. Vertical arrow indicates the western entrance to Port Davey.

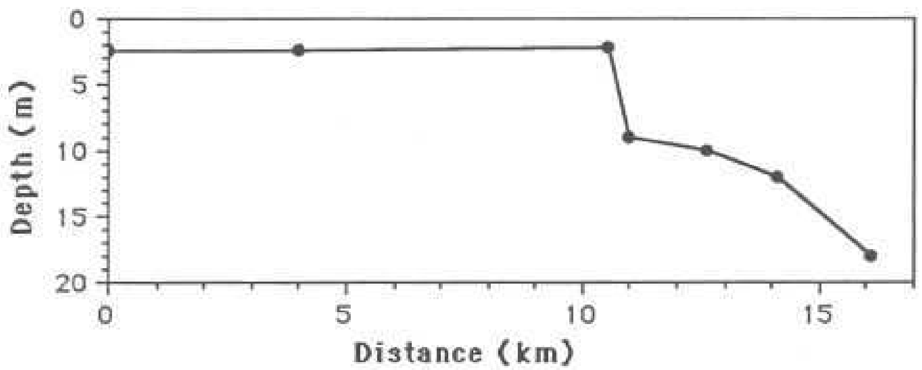


Fig. 3.4. The depth at which benthic algae cover 10% of the reef substratum at seven sites progressing seaward along the Bathurst Harbour estuary from Platypus Point to Shanks Island. Above this depth algal cover is generally high (>50%), while below it the substratum is largely bare with a few sessile animals. The exposed Breaksea Island site has not been included on the graph.

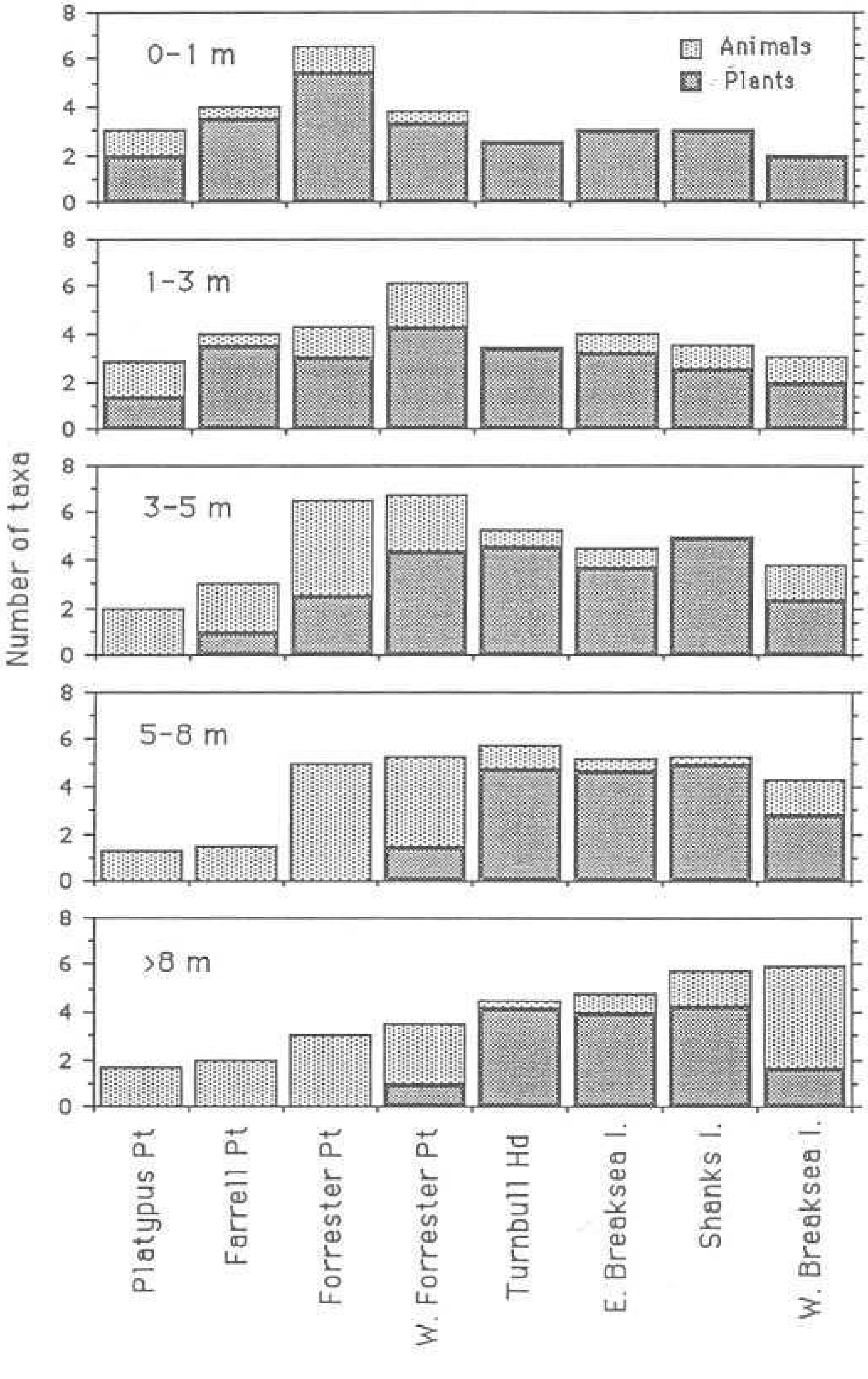


Fig. 3.5. The mean number of species recorded in quadrats at different sites and depths.

greatest diversity at sites was encountered in progressively deeper water (fig. 3.5). Individual taxa also occurred in deeper water as wave exposure increased. *Carpoglossum confluens*, for example, was found within 1 m of the surface at Forrester Point but only in depths of 3-8 m on the east coast of Breaksea Island (fig. 3.3).

The benthic discontinuity at Forrester Point was presumably caused by local water circulation patterns. Hydrological profiles of Bathurst Channel (figures 2.2, 2.3 and 2.4) generally show rapid changes in physicochemical parameters near Sarah Island, hence it is likely that local currents regularly flush Bathurst Channel west of Forrester Point with oceanic water but that the surface water east of this location remains estuarine. The plant assemblages in the estuarine areas of Bathurst Channel would be depauperate for the same reasons as in Bathurst Harbour, viz. low nutrient levels and poor light penetration.

A wave exposure cause for the discontinuity in the benthic community is less likely than hydrological (light and nutrient) one because *Durvillaea antarctica* and other coastal species grow in Bramble Cove, an embayment at the western end of Bathurst Channel which is more sheltered than Forrester Point.

Port Davey:

The little work done in Port Davey during this survey indicates that the benthic flora and fauna of Port Davey is similar in most respects to the benthic biota at sites with similar wave exposure in other areas of southern Tasmania such as Recherche Bay (see Edgar, 1984b, for a general description). However, as described in the previous report (Edgar 1984a), assemblages of sessile animals which are normally found in relatively deep water were found to intrude into shallow water near the western entrance to Bathurst Channel. Even on the exposed west coast of Breaksea Island, a site with little estuarine influence (see Chapter 2), sessile animals such sponges, bryozoans, soft corals and gorgonians were found in high densities in water as shallow as 10 m, with few plants being found below 15 m. Similar faunal assemblages were not observed in the northern section of Port Davey, even though reefs in this area were also subjected to considerable freshwater outflow (from the Davey River). The reefs examined in northern Port Davey disappeared under sand in shallow water and had a low diversity of macroalgae, presumably because of sand scouring.

Kelly Basin:

Contrary to previous anecdotal information, the dominant subtidal plant in Kelly Basin was not a seagrass but a species of green alga *Caulerpa ?alternans*. This plant differs slightly in branching pattern from *Caulerpa alternans*, a rare species known only from Victoria and South Australia. Seagrasses (*Heterozostera tasmanica* and *Ruppia megacarpa*) formed meadows in shallow waters around the western and southern shores of Kelly Basin, however they became very sparse below 1 m, the depth at which *C. ?alternans* became abundant. *Caulerpa ?alternans* formed almost monospecific beds in the western section of Kelly Basin in water depths between 1 and 4 m. The only other plants observed in this zone were occasional specimens of *H. tasmanica, Caulerpa sedoides* and *Caulerpa ?simpliciuscula*. Below 4 m depth, *C. ?alternans* became very patchy. Benthic animals were abundant in the deeper (>3 m) sections of the Basin, with the most important species being the holothurian *Stichopus mollis* and an unidentified ascidian. The bivalve *Electroma georgiana*, the asteroid *Uniophora granifera* and a terrebellid polychaete were also common.

Mobile Invertebrate Fauna

A total of 340 invertebrate species was collected from the Port Davey estuary during the artificial algal sampling program. The identified taxa are listed in appendix 3. The number of species collected in samples was highest at Breaksea Island, Port Davey (243 species), and declined up the estuary to Bathurst Harbour (Celery Top Islands, 51 species; Dixon Island, 29 species; the mouth of the Old River, 26 species). The major decrease in species numbers occurred in Bathurst Channel between Sarah Island (222 species) and Bathurst Narrows (92 species). The most diverse assemblages at Sarah and Breaksea Islands were found at 4 m depth, however little difference was evident in the number of species at different depths at other sites (figures 3.6 and 3.9). The four major animal groups (amphipods, other crustaceans, molluscs and polychaetes) were all approximately equal in species numbers at each site (fig. 3.6).

Location within the estuary rather than water depth had by far the greatest effect on mobile invertebrate assemblages. The major dichotomy in the heirarchical classification of sites using mobile invertebrate data separated the Sarah Island and Breaksea Island sites from the other four sites (fig. 3.7). Most of the abundant species collected at Sarah Island and Breaksea Island were marine species commonly collected in such habitats as kelp holdfasts elsewhere in southern Tasmania (see e.g. Edgar 1987). The next major divisions between sites were between the Bathurst Harbour and the Bathurst Narrows sites, and between the Sarah Island and Breaksea Island sites. All of the samples collected at 1 m depth in Bathurst Harbour grouped together at a very low level of similarity, indicating that the Bathurst Harbour fauna was relatively homogeneous.

The inverse classification showed an analagous result to the classification of sites with three major groupings of invertebrates (fig. 3.8). These three groupings corresponded closely with location. Group A consisted primarily of species associated with the two sites influenced by oceanic water, Group B consisted of species found in Bathurst Channel and Group C consisted of Bathurst Harbour species (table 3.1). A fourth group contained only one species, *Amaryllis macrophthalma*. This species was not collected from any samples at 1 m depth but was widespread throughout the estuary in deeper water.

The three major groups of invertebrates showed high fidelity to location with little seasonal movement up and down the estuary in response to changes in salinity. A few Group B (Bathurst Channel) species did move into Bathurst Harbour during February (fig. 3.9), however more Group B species were also found at Sarah Island and Breaksea Island in February than at other times. The expansion of Group B animals thus was both up and down the estuary during summer. The greatest number of Group C (Bathurst Harbour) species in Bathurst Channel were also collected in February, in contrast to their expected downstream movement during the winter period of peak freshwater outflow. The summer (February) period was clearly the mc favourable season for almost all species. Overall species richness was highest at all sites and all depths at this time (fig. 3.8).

The abundances of mobile animals were also highest during February at the Bathurst Channel and Port Davey sites (fig. 3.10). In contrast, animals were most abundant at all shallow Bathurst Harbour sites during November.

Animal numbers decreased very rapidly with depth in Bathurst Harbour, whereas at Breaksea Island there was little difference in the abundances of animals at different depths. The two Bathurst Channel sites showed intermediate patterns, with many more animals at 8 m depth at Sarah Island than at Bathurst Narrows.

The most parsimonious hypothesis to explain the negative relationship between anim. numbers and depth is that invertebrate population densities are primarily regulated by the production of microalgal food resources, which in turn is dependent on the level of available light. Because considerable light penetrates to 8 m at Breaksea Island, invertebrate densities are high at that depth, whereas negligible light penetrates to 8 m depth at Bathurst Harbour for much of the year, so animal numbers are correspondingly low. Suspended particles apparently supplied little food to animals associated with artificial algae; very few animals were present at 8 m depth in Bathurst Narrows, the location with the strongest current flow (≈1 knot). The above hypothesis also explains the concordance in the seasonal patterns of abundance of epifauna at Celery Top Island with the seasonal change in the numbers and biomass of surface zooplankton (figures 4.4 and 4.5). Seasonal production of planktonic and benthic invertebrates should coincide because the two groups are linked through microalgae to seasonal changes in light and nutrients.

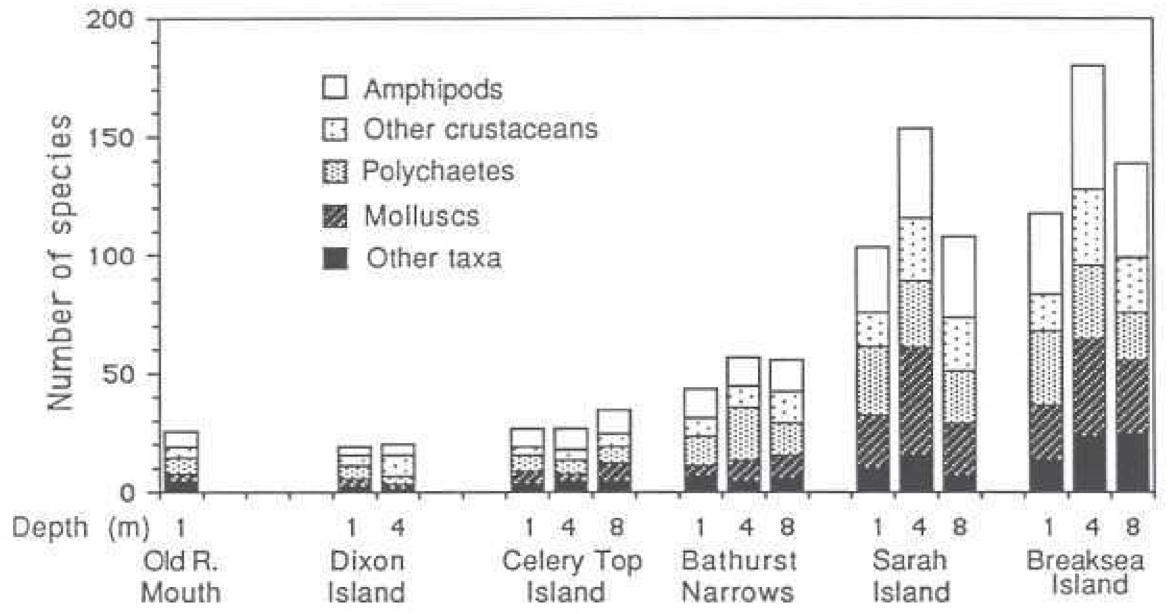


Fig. 3.6. The total number of invertebrate species collected from artificial algal clumps placed at six sites and at three depths.

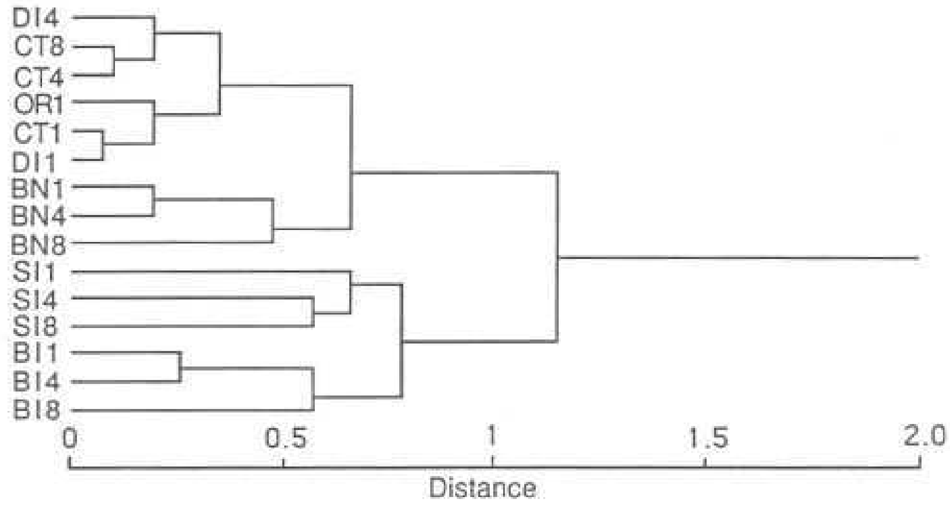


Fig. 3.7. Heirarchical classification using invertebrate abundance data of the locations and depths at which artificial algae were placed. Sites are indicated as Old River Mouth (OR), Dixon Island (DI), Celery Top Island (CT), Bathurst Narrows (BN), Sarah Island (SI) and Breaksea Island (BI), with the last digit indicating depth.

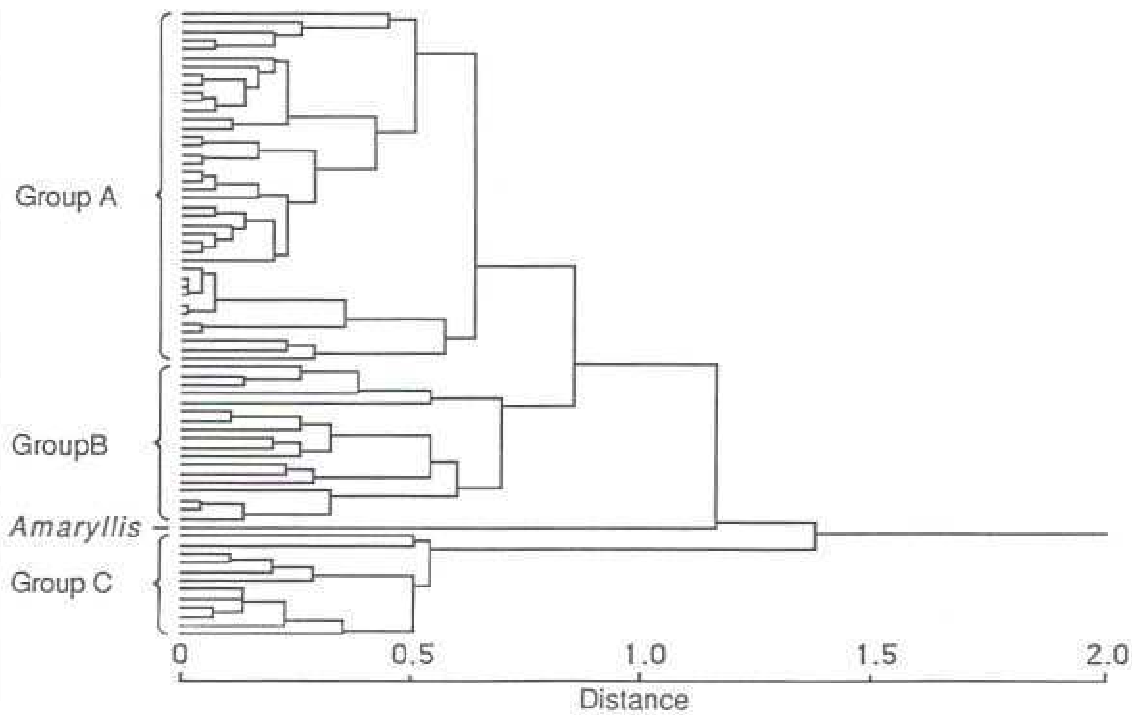


Fig. 3.8. Heirarchical classification into four species groups of 71 common invertebrate species collected during the study. The species present in each group are listed in table 3.1.

Table 3.1. The abundances of the most common species collected during the study from artificial algal clumps. Species are arranged in Species Groups A, B, C and D as indicated by the inverse classification. Taxa are indicated by letters as follows: Amphipoda (A), Isopoda (I), Tanaidacea (T), Decapoda (D), Gastropoda (G), Insecta (S), Pycnogonida (Y), Ophiuroidea (O), Platyhelminthes (H), Polychaeta (P).

Species	Taxon	Old R. Mouth	Dixon I.	Celery Top I.	Bathurst Narrows	Sarah I.	Breaksea I.
Group A							
Lembos clematis Moore	A			2		143	
Hyale ?kandari Barnard	A					756	158
Maera viridis Haswell	A					26	153
Eusiroides sp.	A					202	57
Mallacoota carteta Barnard	A					21	1113
Mallacoota diemenensis (Haswell)	A					378	532
Podocerus sp.	A				4	63	88
Hyale sp.	A						480
Aora ?mortoni (Haswell)	A						124
Tethygeneia sp.	A						85
Gammaropsis thomsoni Stebbing	A					39	58
Eusirid sp. 2	A					93	110
Podocerid sp.	A				15	30	34
Amphilochid sp.	A						20
Jassa sp.	A					1	33
Paradexamine churinga Barnard	A					56	9
Proto sp.	A						256
Leptochelia ?ignota Chilton	T				2	40	
Hippolyte sp.	D					23	15
Paracilicaea hamata (Baker)	I					46	2
Haswellia emarginata (Haswell)	I					10	126
Uromunna sp.	I				2	21	24
?*Pleurogonium* sp.	I					20	6
Asellota sp. 1	I						31
Eatoniellid sp.	M					65	14
Eatoniella sp. 1	M					75	16
Eatoniella sp. 2	M					84	31
Pisinna circumlabra Ponder & Yoo	M					651	77
Alvania suprasculpta May	M					21	3
Pisinna frenchiensis (Gat. & Gab.)	M					76	46
Cystiscus angasi (Crosse)	M				4	17	27
Macrozafra fulgida (Reeve)	M				1	38	26
Cantharidella tiberiana (Crosse)	M					69	159
Ophiuroid sp.	O					23	86
Amphipholis squamata Delle Chiaje	O				1	24	30
Platyhelminthes sp.	T				3	10	8
Pionosyllis sp. 1	P			1	5	2	14
Hesionid sp.	P				18	65	95
Polynoid sp. 1	P				2	29	120
?*Typosyllis* sp.	P					2	126

Table 3.1. (Cont.).

Species	Taxon	Old R. Mouth	Dixon I.	Celery Top I.	Bathurst Narrows	Sarah I.	Breaksea I.
Group B							
Paradexamine cf. *thadalee* Barnard	A	6	2	4	244	231	146
Parawaldeckia yamba Barnard	A				264	14	8
Aora maculata (Thomson)	A			2	952	3	
Tethygeneia sp.	A				117	48	298
Stenothoid sp.	A				36	152	12
Haplocheira barbimana (Thomson)	A					73	1
Halicarcinus ovatus (Stimpson)	D	1	2	4	33	35	38
?Ianiropsis sp.	I				589	268	18
Dentimitrella cf. pulla (Gaskoin)	G			1	44	17	4
Amphithalamus luteofuscus (May)	G					48	
?*Spurilla macleayi* (Angas)	G	1		1	101	20	13
Pycnogonida sp.	Y				106	3	
Platynereis dumerillii antipoda Hartman	P	8	13	18	155	109	17
Neanthes valii Kinberg	P	2	4	15	42	4	1
Phyllodoce sp.	P	2	4	5	12	6	5
Chrysopetalum sp.	P			2	32	115	20
Pionosyllis sp. 2	P					25	1
Armandia sp.	P				18	61	26
Group C							
Paramoera sp.	A	113	1145	4259	1248	6	1
Eusirid sp. 1	A	947	87	201	44		
Melita cf. *inaeqistylis* (Dana)	A	55		11	65		
Paracorophium excavatum (Thomson)	A	161		3			
Cymadusa sp.	A	167	25	349	242	1	
Macrobrachium sp.	D	6	11	11	1		
Ischyromene rubida (Baker)	I	55	84	648	102	1	
Tatea rufilabris (Adams)	G	907	294	348	1		
Hydrobia buccinoides (Quoy & Gaimard)	G	16	72	2	1		
Notoacmaea flammea (Quoy & Gaimard)	G	14	10	13	10	1	
Pontomyia sp.	S	5		19	28		
Polynoid sp. 2	P	144	256	408	842	169	40
Group D							
Amaryllis macrophthalma Haswell	A		39	215	9	18	40

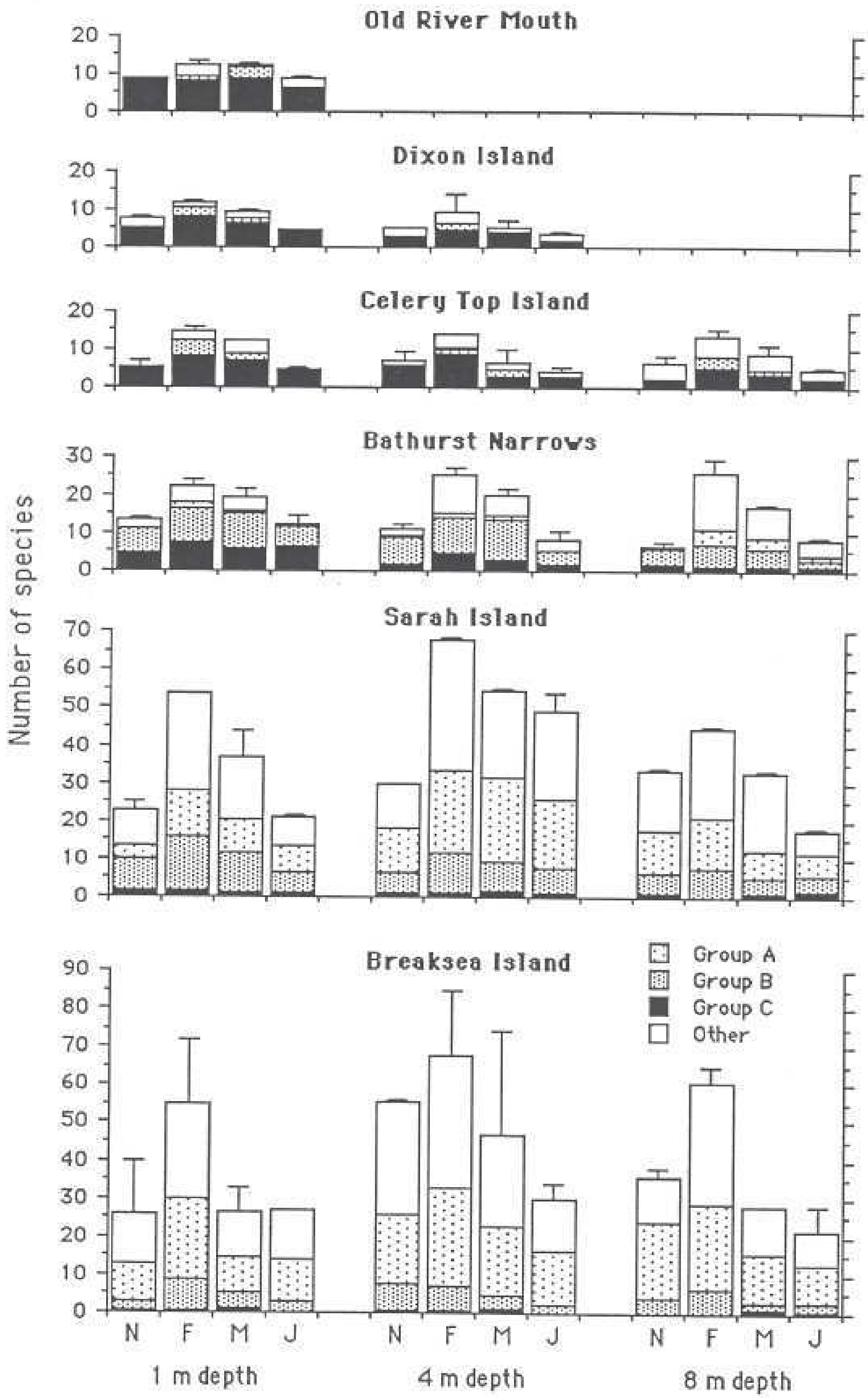


Fig. 3.9. The mean number of species (± s.d.) collected per artificial algal clump from the six sites during the November (N), February (F), May (M) and July (J) sampling trips. The 'other' category includes *Amaryllis macrophthalma* plus species not listed in table 3.1.

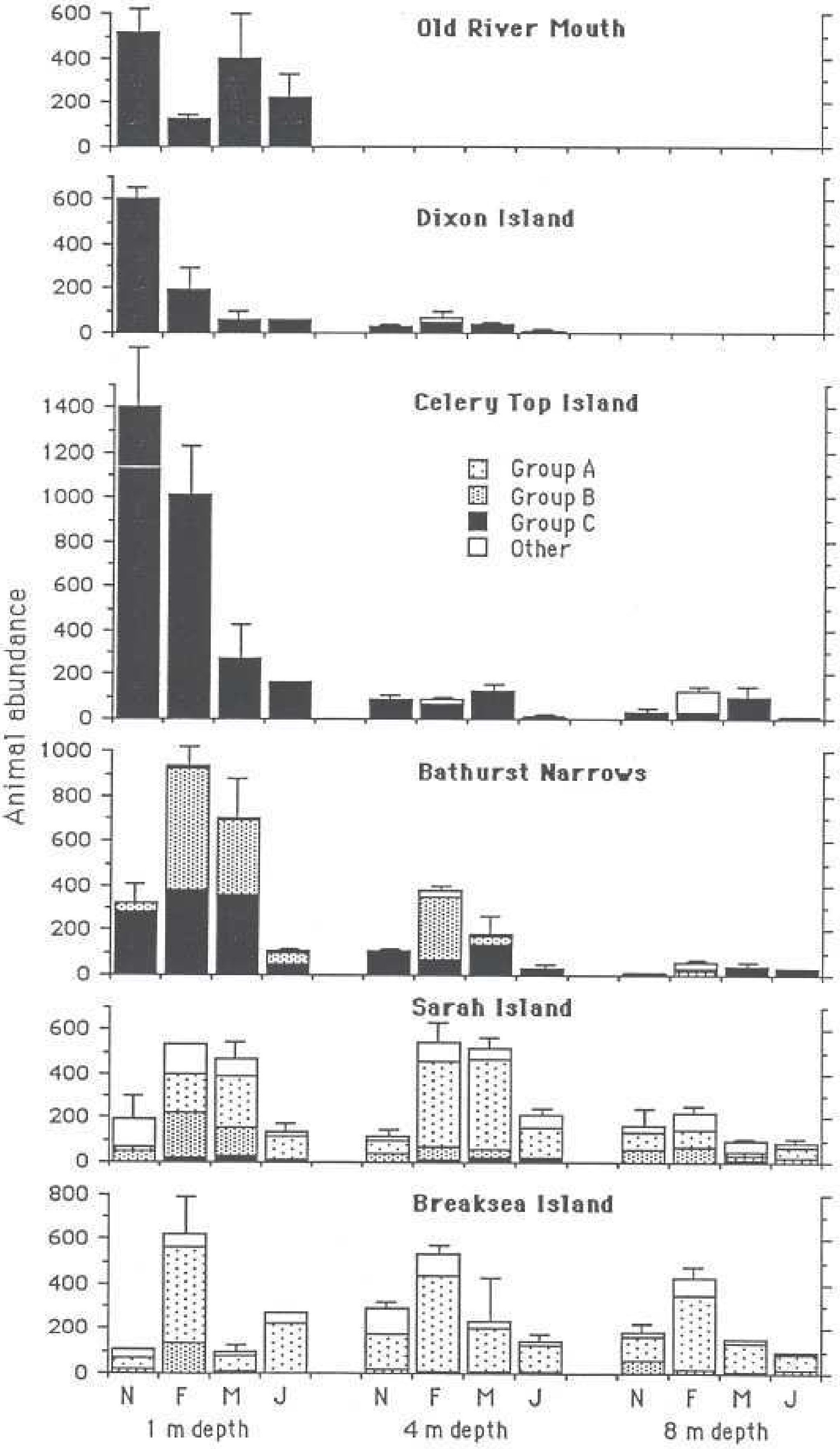


Fig. 3.10. The mean number of animals (± s.d.) collected per artificial algal clump from the six sites during the November (N), February (F), May (M) and July (J) sampling trips. The 'other' category includes *Amaryllis macrophthalma* plus species not listed in table 3.1.

Chapter 4: **Plankton**

Introduction

Apart from an unusual cyclopoid copepod which was collected from the western outlet of Bathurst Channel during a summer field trip by the Biological Society of the University of Tasmania (Ong 1969), nothing was known about the planktonic inhabitants of the Bathurst Harbour estuary before this study. The Biological Society failed in attempts to collect plankton from sites further upstream, so they concluded, incorrectly as it turns out, that the estuary has a negligible abundance of plankton. This absence of studies in Bathurst Harbour contrasts greatly with the considerable body of information on the plankton of the Derwent and Huon River estuaries (Nyan Taw & Ritz 1978, 1979; Ong 1967), the two other large estuaries in southern Tasmania.

In order to partly redress this lack of knowledge, samples of zooplankton and phytoplankton were collected in association with hydrological data during five surveys between October 1988 and July 1989. Because the investigation was limited by time and resource restrictions, it has been designed only as a preliminary one. The primary aim of the study has been to describe the gross distribution patterns of zooplankton and phytoplankton within the estuary.

Methods

Plankton samples were collected using a 220 mm diameter 20 µm mesh plankton net which was towed slowly behind a runabout dingy for 120 s intervals. Collections were made at the major hydrological stations (fig. 2.1) along the transect from Bathurst Harbour to Port Davey: Stations 3 (Bathurst Harbour 2), 5 (Platypus Point), 6 (Farrell Point), 7 (Branson Point), 8 (Sarah Island), 9 (Breaksea Island East) and 10 (Breaksea Island West). Two replicate samples were collected from surface waters at each site during the December, February, May and July surveys, with unreplicated samples being made on 8 October 1988 and no sample being collected off Branson Point on that date. Once each sample was collected and the 50 ml sample bottle unscrewed from the net, the contents were preserved for later analysis by the addition of buffered formalin. A General Oceanics Model 2030 Digital Flowmeter which was fitted into the mouth of the net during the 25 July 1989 survey indicated that the mean velocity of water passing through the centre of the net was 11.5 cm/s, hence the net filtered ≈0.5 m^3 of water during each 120 s sampling period.

In the laboratory, two 0.3 ml aliquots from each shaken sample were placed under cover slips on separate microscope slides, and the abundances of planktonic taxa recorded while scanning four times across the slides using the 10x objective of a compound microscope. Whenever the numbers of zooplankton were low (i.e. <50 planktonic organisms were recorded during the scanning of a slide), the zooplankton in the primary sample was also sorted and counted under a dissecting microscope. Plankton counts on microscope slides were converted to total sample counts by multiplying by a factor of 182; the regression $P = 182 \times S$ ($n = 11$, $r^2 = 0.80$) was calculated from the December data, where P is the zooplankton abundance recorded from a sample by direct count and S is the number of zooplankton taxa recorded during a total of eight traverses across the two slides from each sample. The biomass of zooplankton in each sample was determined by rinsing a 5 ml subsample in freshwater, passing it through a 0.52 µm Millepore filter and then calculating the difference between the predried and postdried (at 60 °C for 2 hours) weight of the filter.

Results

The phytoplankton community in Bathurst Harbour is impoverished in species, particularly during the winter and spring months when the dinoflagellate *Dinophysis acuminata* occurs in bloom proportions. On the October and July surveys *D. acuminata* provided >99% of sampled phytoplankton at the Bathurst Harbour and Platypus Point sites, with the diatoms *Nitzschia* sp. and *Chaetoceros* sp. being the only other species recorded. During summer two other dinoflagellates, *Gyrodinium* cf. *uncatenum*. and *Protoperidinium* cf.*bipes*, were almost as abundant as *D. acuminata*, with a number of diatoms also being present. The low algal species richness of Bathurst Harbour is perhaps most clearly indicated by the very low numbers of dinoflagellate cyst species in sediment cores from the area; cores collected near Celery Top Island Island and Dixon Island contained only *Gonyaulax grindleyi*, *Scrippsiella trochoidea*, *Protoperidinium oblongum* and *Polykrikos schwartzii*, a very low number of taxa compared with cores collect elsewhere in Tasmania such as the Derwent and Huon estuaries (G. Hallegraeff, pers. comm.).

The number of phytoplankton species was clearly influenced by the amount of marine water present. Algal species richness increased towards the western outlet of Bathurst Channel and in the months of warmer water temperatures (fig. 4.1). At the time of the February intrusion of marine water into Bathurst Harbour, there was little change in observed algal species richness along the estuary. This lack of an increase in species numbers towards Port Davey during summer may nevertheless have been an artifact of the small sample sizes examined; several oceanic algae, such as the dinoflagellates *Phalacroma rotundatum*, *Ceratium massiliense*, *Ceratium furca* and *Ceratium asymmetricum*, were collected in low numbers off Breaksea Island but not detected upstream of Sarah Island in Bathurst Channel, even during summer.

The two major components of the phytoplankton, dinoflagellates and diatoms, showed almost mirror image patterns of abundance on both spatial and temporal scales (fig 4.2). Dinoflagellate numbers declined in importance from Bathurst Harbour towards Port Davey while diatoms showed the opposite trend (fig. 4.3). Dinoflagellates were also most abundant during the three surveys in the cooler months, whereas diatoms were present in large numbers throughout the estuary only during summer.

In contrast to the hydrological data which showed that the pattern in February was markedly different from the patterns recorded on other sampling occasions, the planktonic data indicate a major dichotomy between the distribution of plankton in December/February and in May/July/October. This dichotomy is apparent for phytoplankton (fig. 4.3) but is more clearly seen for zooplankton (figures 4.4 and 4.5).

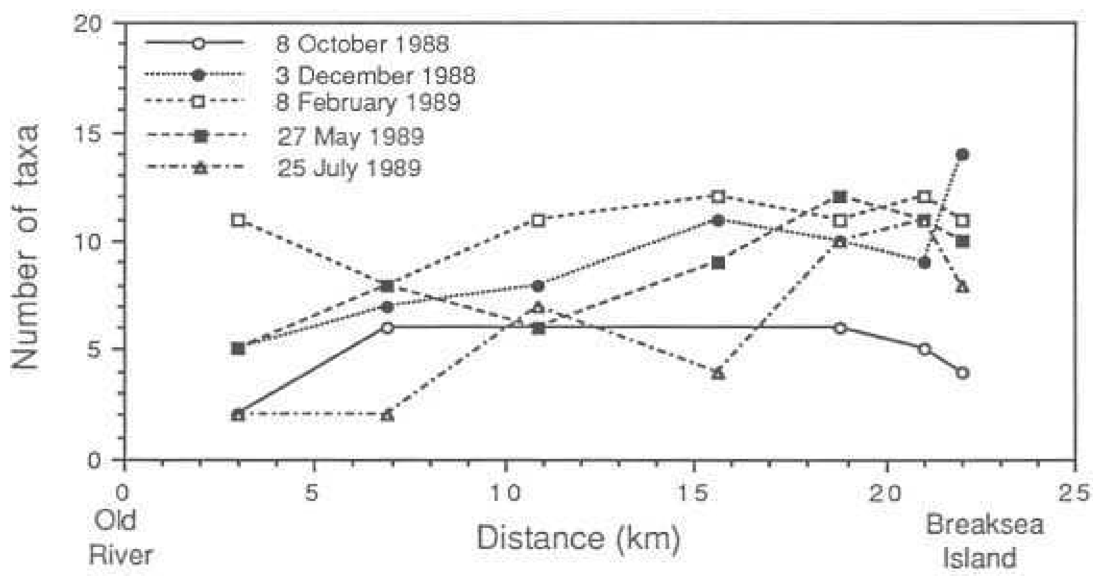


Fig. 4.1. Number of phytoplankton taxa observed on microscope slides prepared from samples collected at sites along the Bathurst Harbour estuary on various dates.

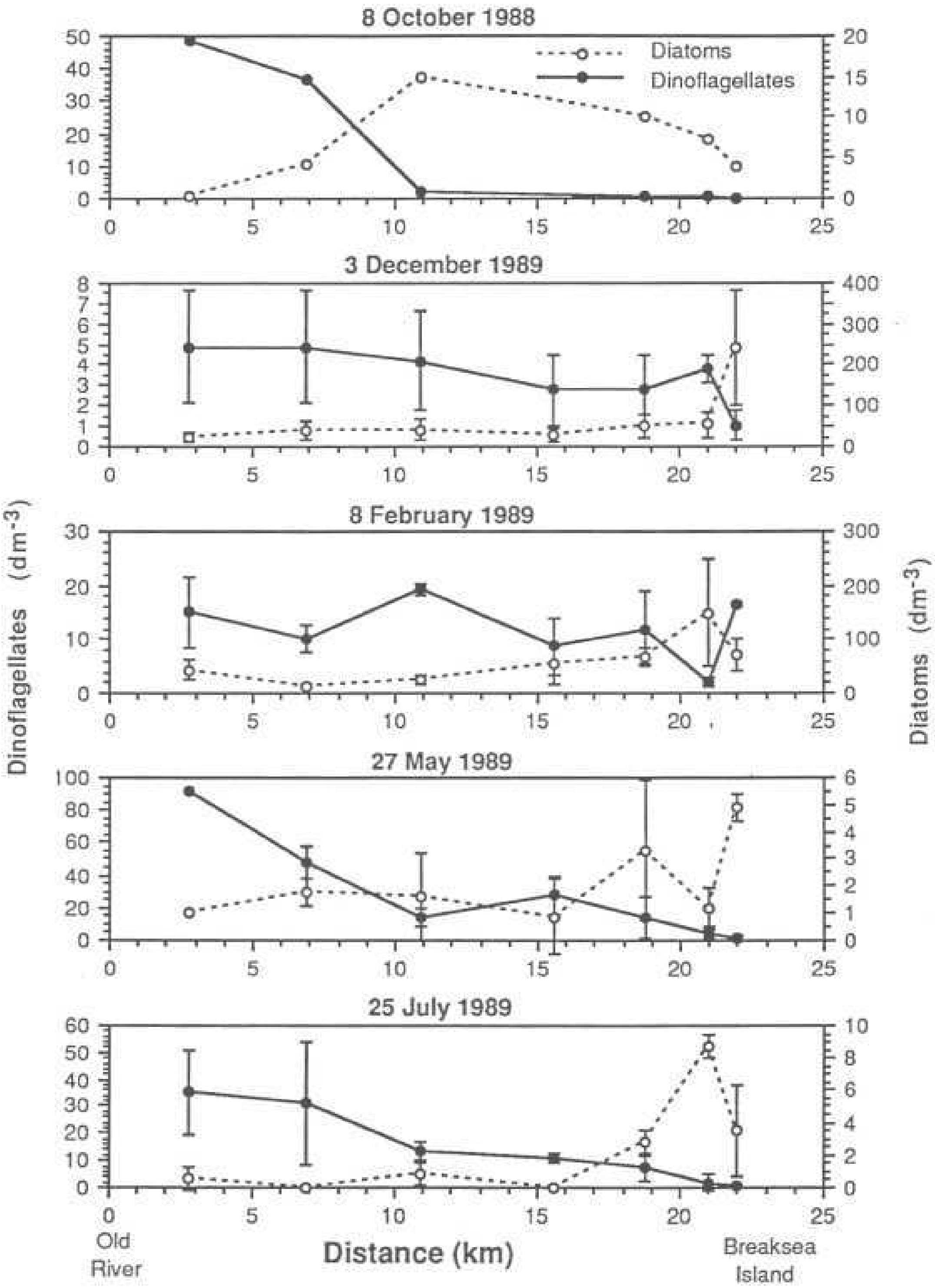


Fig. 4.2. Densities (± s.d.) of dinoflagellate and diatom cells along the Bathurst Harbour estuary on various sampling dates.

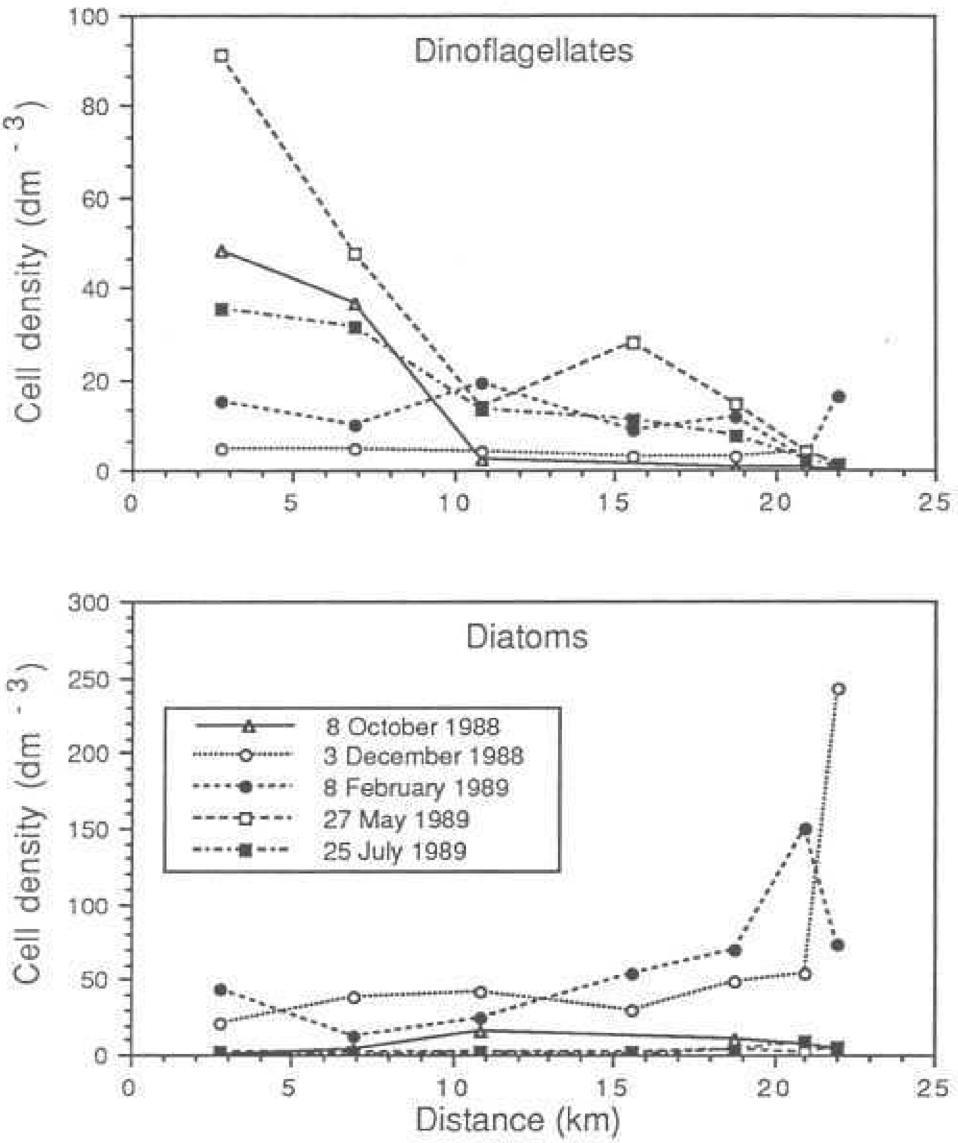


Fig. 4.3. The mean densities of dinoflagellate and diatom cells at sites along the Bathurst Harbour estuary on various sampling dates.

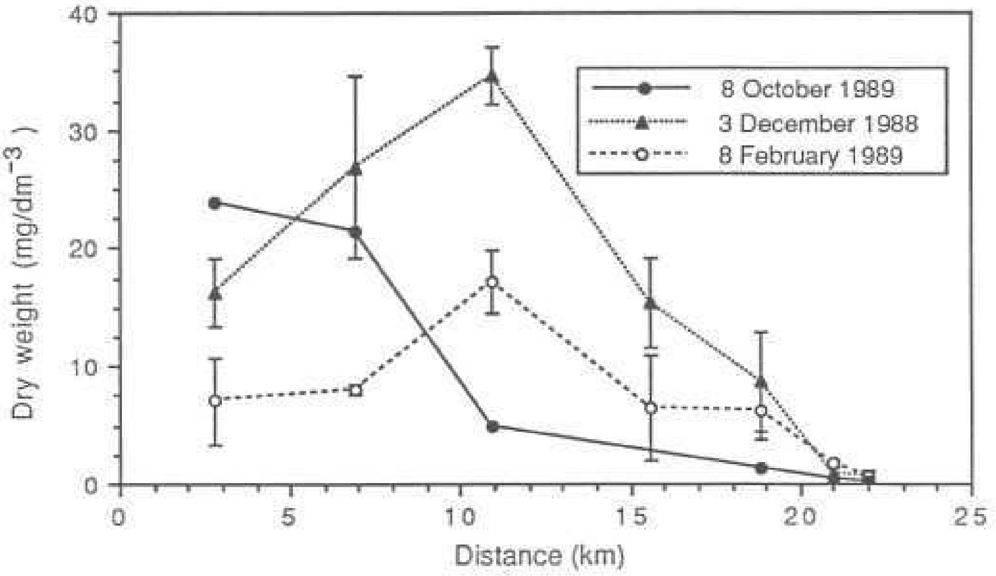


Fig. 4.4. The mean biomass of zooplankton at sites along the Bathurst Harbour estuary on various sampling dates. Zooplankton biomass was negligible (<1 mg/dm^3) at all sites on 27 May 1989 and 25 July 1989 so has not been shown here.

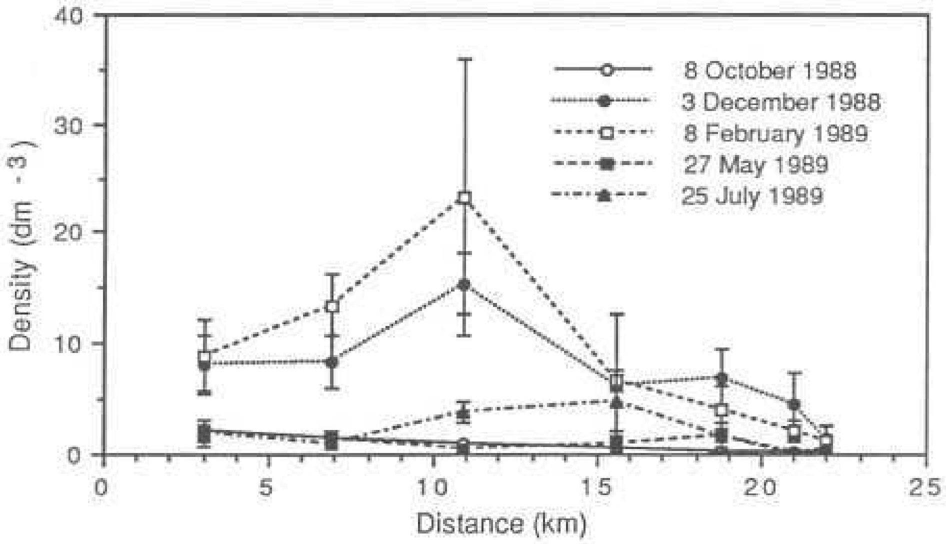
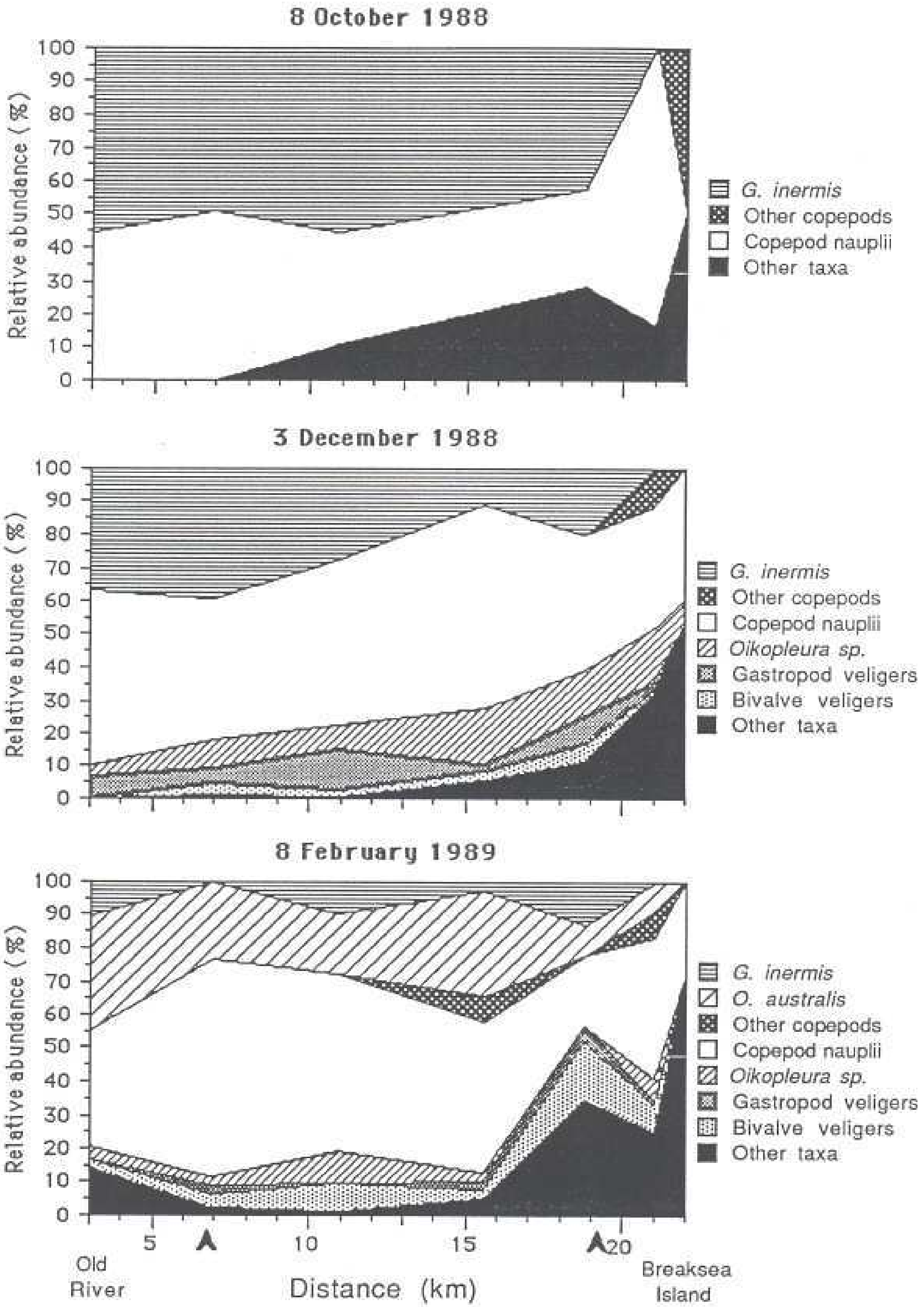


Fig. 4.5. The mean abundance of zooplankton at sites along the Bathurst Harbour estuary on various sampling dates.

Zooplankton biomass (fig. 4.4) and abundance (fig. 4.5) both peaked in December and February. The patterns of distribution of zooplankton biomass and abundance did not, however, precisely correspond with each other because the dominant species in October and December, the copepod *Gladioferens inermis,* grew several times larger and more than an order of magnitude heavier than the major species from February to May, the copepod *Oithona australis*. Consequently zooplankton biomass was highest in December while zooplankton were most abundant in February. Zooplankton biomass was also very high in Bathurst Harbour during October, a time of relatively low zooplankton abundance. The low average body size and low numbers of zooplanktonic taxa in May and July resulted in the biomass of samples from those surveys being virtually undetectable.

The distribution of zooplankton biomass along the Bathurst Channel transect did not differ between the two summer surveys, except that biomass had consistently decreased from December to February by ≈50% at all sampling sites (fig. 4.4). The maximum biomass of zooplankton, and also maximum animal numbers, were recorded at Farrell Point in Bathurst Channel, a site implicated in the hydrological surveys to have a slight upwelling.

During the two summer surveys, the zooplankton community was much more diverse than on the other three surveys, with a large meroplanktonic component (fig. 4.6); large numbers of bivalve and gastropod veligers and lesser numbers of polychaete, shrimp and crab larvae and hydromedusae were recorded in summer. The dominant copepod species *Gladioferens inermis* became less important than the cyclopoid *Oithona australis* between December and February. Prior to summer *G. inermis* was virtually the only copepod species recorded from Bathurst Harbour and the eastern end of Bathurst Channel, while from February to July a number of other taxa, most notably *Paracalanus indicus* and *Acartia sp.*, were present in addition to *G. inermis* and the dominant *O. australis* (fig. 4.6). In addition to the two main copepod species, one other species, the appendicularian *Oikopleura* sp., was abundantly collected during the surveys. *Oikopleura* sp. was common throughout the Bathurst Harbour estuary between December and May, especially during summer. The category "other taxa" shown in fig 4.6 consisted largely of unidentified planktonic eggs and was most important towards Port Davey.



8 October 1988
Relative abundance (%)
G. inermis
Other copepods
Copepod nauplii
Other taxa
3 December 1988
Relative abundance (%)
G. inermis
Other copepods
Copepod nauplii
Oikopleura sp.
Gastropod veligers
Bivalve veligers
Other taxa
8 February 1989
Relative abundance (%)
G. inermis
O. australis
Other copepods
Copepod nauplii
Oikopleura sp.
Gastropod veligers
Bivalve veligers
Other taxa
Old River
Distance (km)
Breaksea Island

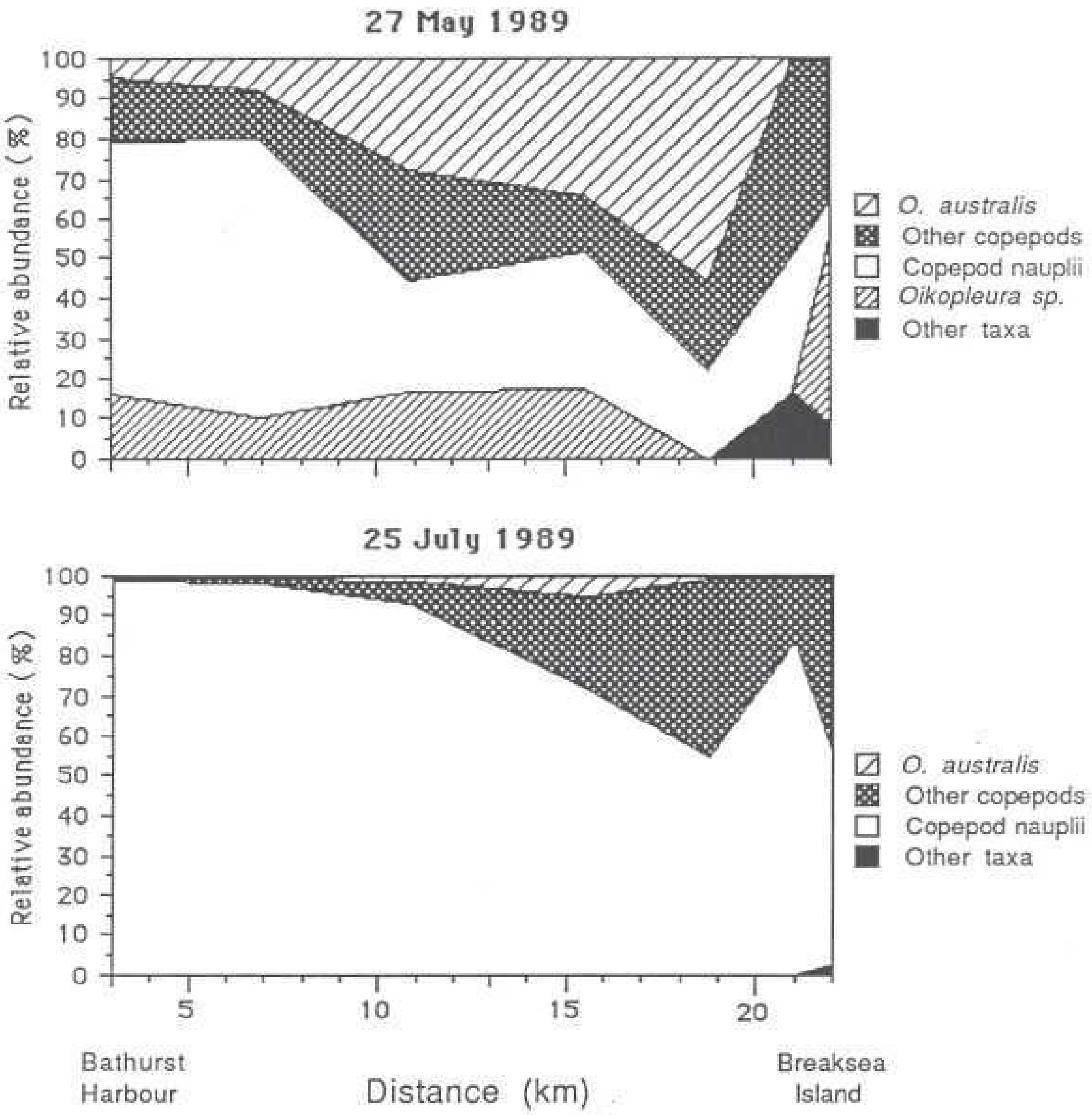


Fig. 4.6. Relative abundance of major zooplankton taxa along the Bathurst Harbour estuary on various sampling datea.

Discussion

The absolute abundance data shown in the various figures has probably been underestimated due to various systematic errors, so these data can be compared with other studies only with caution. However, because any errors should be constant for different sites and sampling periods, the numerical data can be directly compared between sites and seasons. The two largest possible sources of error are (i) the sampling vials attached to the net did not have drainage windows, hence the net could not be washed down and some water with organisms was lost when the sampling vials were unscrewed, and (ii) calculations of the water sieved through the net were based on water passing through the centre of the net, with the reduction in water flow due to drag near the edges of the net not being accounted for.

In a recent review, Cushing (1989) summarised a number of general differences between planktonic communities in stratified and unstratified waters throughout the world. He noted that phytoplankton communities in strongly stratified waters are characterized by a predominance of dinoflagellates while diatoms are most common in weakly stratified water. Cushing (1989) postulated that, because dinoflagellates are mobile, they can position themselves near the water surface in stratified waters during the day to exploit the high light levels. Poorly stratified waters, on the other hand, are dominated by diatoms because these algae reproduce quickly and have lower photosynthetic requirements than dinoflagellates. Surface turbulence in unstratified water was thought to cause large numbers of phytoplankton to be transported to depths with little light for growth. Cushing (1989) also noted that zooplankton biomass dramatically increases whenever thermoclines in temperate waters are overturned in spring, the time when phytoplankton communities change from being dominated by dinoflagellates to being dominated by diatoms. He interpreted these patterns in terms of Azam *et al.*'s findings (1983) that dinoflagellates were rarely a major food source for herbivorous zooplankton. In environments dominated by dinoflagellates, the major trophic pathway to zooplankton is an indirect one, through bacteria, heterotrophic flagellates and ciliates, which is largely fueled by the organic matter excreted by the dinoflagellates. Because of the number of trophic links through this microbial food loop, it supports much lower zooplankton production than the direct diatom-copepod trophic linkage.

The patterns of distribution of planktonic organisms in the Bathurst Harbour estuary generally agreed with these world-wide patterns; dinoflagellates declined in importance from the stratified waters of Bathurst Harbour to the turbulent waters of Port Davey, and also from the winter season when a well-defined halocline was present in Bathurst Harbour to the summer season when a halocline was lacking.

The timing of the Bathurst Harbour phytoplankton and zooplankton successions did not, however, agree with the classical model because zooplankton had increased to high biomass levels by October 1988. The rapid buildup in zooplankton biomass in spring (and presumably greatly increased production) therefore must have been fueled by dinoflagellates and associated smaller organisms rather than by diatoms, or else the phytoplankton community was extremely unstable and not adequately described using samples collected at bimonthly intervals.

In common with other systems, dinoflagellates were unlikely to have provided much direct food for zooplankton in Bathurst Harbour, even during the period when dinoflagellates occurred in high abundances. The major dinoflagellate species, *Dinophysis acuminata*, appeared much too large to be ingested by zooplankton, hence a microbial food loop consisting of bacteria, small (<20μm) phytoplankton and ciliates was probably providing most of the food for zooplankton during the dinoflagellate blooms. This hypothesis is supported by the large numbers of appendicularians present in Bathurst Harbour; this animal group is known to feed almost exclusively on organisms less than 5μm (Knoechel & Steel-Flynn 1989).

The succession of the major plankton groups in the Bathurst Harbour estuary can be summarised as follows (table 4.7).

Table 4.7. Seasonal abundance of major planktonic groups in Bathurst Harbour. Increasing abundances indicated by increasing number of +'s.

Season	Dinoflagellates	Diatoms	Bacteria, ciliates and flagellates	Copepods
Winter	+ + +	+	+ +	+
Spring	+ + +		+ + + +	+ + +
Summer	+	+ + +	+	+ + + +
Autumn	+ + +	+	+	+

The reasons for the low densities of dinoflagellates in summer and low densities of diatoms in other periods of the year remain to be determined. Cushing's (1989) hypothesis does not explain the decline in dinoflagellate densities in summer because the estuary is quite shallow with considerable light penetrating to the bed of the estuary in February. Moreover, the estuary was stratified on 3 December 1988 when dinoflagellate numbers were low. The abundances of dinoflagellates were therefore more likely to have been limited by a lack of nutrients or trace elements rather than light during summer, possibly because diatoms were more efficient at utilizing the available nutrients due to their greater surface area/volume ratio. Bathurst Harbour shows all the characteristics of a nutrient deficient estuary. Very low levels of nitrates were recorded in surface waters throughout the year, although it should be noted that nitrate concentrations were no lower in summer than during spring when dinoflagellate numbers were high. A deficiency of phosphates rather than a lack of nitrates therefore possibly restricted dinoflagellate growth.

The density of diatoms was probably severely curtailed in Bathurst Harbour during the winter months because of the lack of accessible nitrogen in surface waters and the lack of light penetration to the deeper waters. Because dinoflagellates are motile, they would not be similarly restricted; they can move between the well lit surface layer and the nitrate rich waters below the chemocline (Eppley et al. 1968, Blasco 1978). The few phytoplankton samples collected during the study from waters below 2 m depth contained very few organisms (unpublished data); dinoflagellates were clearly concentrated within 1 m of the surface during the day. Other possible explanations for the low numbers of diatoms are that growth was limited by a deficiency of silica, phosphorus or trace elements in the estuary.

While the high abundance and biomass of copepods during summer was presumably dependent on diatom production, the reasons for the increase in copepod abundance prior to the October survey remain equivocal. Dinoflagellate densities were high throughout winter; it is therefore possible that picoplankton and nanoplankton were sufficiently productive during winter to sustain increased copepod production. As well as utilizing exudates from dinoflagellates, planktonic bacteria may also have been directly utilizing the leached organic compounds present in freshwater entering the estuary. The quantity of dissolved organic compounds entering Bathurst Harbour must be large, judging by the considerable amount of foam present along surface slicks in the area.

Chapter 5: **Fishes**

Introduction

The fish fauna of the Port Davey/Bathurst Harbour region is much better known than the invertebrate fauna, largely because of recent surveys conducted by B. Hutchins (Museum of Western Australia) and P. Last (Tasmanian Fisheries Development Authority). A checklist of fish species recorded during these surveys and other sources is provided by Edgar (1984a). In addition to these fishes, three unusual species were collected from the Port Davey region by Hutchins and Last but have not been listed previously because of taxonomic uncertainties. These fishes are (i) an undescribed brotulid, *Microbrotula* sp., which has not been recorded elsewhere, and (ii) an antennariid which is close to *Phillophryne scortea* (McCulloch & Waite) but differs in several characteristics from the holotype and may or may not be a new species, and (iii) an undescribed bovichthyid belonging to a new genus. This species was collected using rotenone from a cave at the western entrance to Bathurst Channel and has also recently been collected from caves off Tasman Peninsula and Wilsons Promontory (P. Last, pers. comm.).

A total of 73 fish species has thus been collected from the Port Davey/Bathurst Harbour region. The ichthyofauna is clearly a depauperate one, situated as it is at the southernmost margin of Australia. One notable feature of the Port Davey ichthyofauna identified by Edgar (1984a) was that a small component of net-susceptible species was present; these fishes are now virtually absent from the populous eastern and northern coasts of Tasmania.

Methods

Seine Netting

Fishes were collected using a 50 m long beach seine (12 mm mesh) set in a semicircular arc from the beach. A total of 24 sites from Bathurst Harbour to Kelly Basin were sampled from 27 to 29 July 1989, 23 of these sites from 16 to 18 February 1989, and 18 sites from 29 to 30 November 1988. The locations of the sites are shown in fig. 5.1 and the water temperatures and salinities at the times of the February and July surveys are listed in table 5.1. The abundances of fishes at each site were recorded using a log 3 abundance ranking scale (i.e. 1 individual was recorded as 1, 2-3 individuals as 2, 4-9 individuals as 3, 10-27 individuals as 4, 28-81 individuals as 5, 82-243 individuals as 6, etc.). Two replicate hauls were conducted at each site.

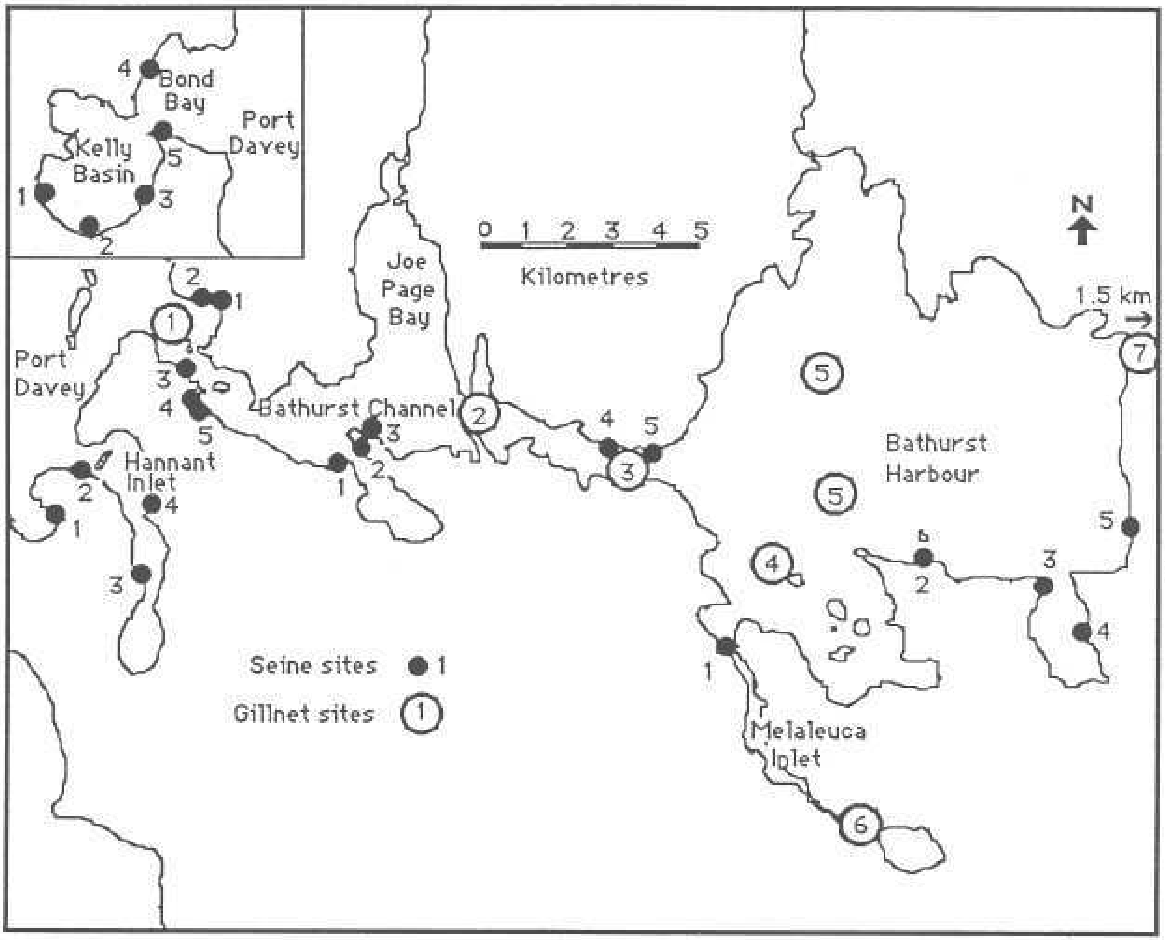


Fig. 5.1. Locations of fish sampling sites. Seine sites are separately numbered in five areas: Kelly Basin, Hannant Inlet, West Bathurst Channel, East Bathurst Channel and Bathurst Harbour (see table 5.1). Gillnet site 1: Western Bathurst Channel; gillnet site 2: Bathurst Narrows; gillnet site 3: Eastern Bathurst Channel; gillnet site 4: Celery T Islands; gillnet site 5: Bathurst Harbour; gillnet site 6: Melaleuca Inlet; gillnet site 7: Old River.

Gillnetting

Gillnets (50 m long, 110 mm mesh) were set overnight in seven areas along the Bathurst Harbour estuary: Old River, Melaleuca Inlet, Bathurst Harbour, Celery Top Islands, Eastern Bathurst Channel, Bathurst Narrows and Western Bathurst Channel (see fig. 5.1) Four replicate nets were generally set in each area during the five field trips (October 1988, November/December1988, February 1989, May 1989 and July 1989), with the following

Table 5.1. Hydrological characteristics of the sites used for beach seining.

Area	Locality	Temperature (°C)		Salinity (°/oo)	
		Feb.	Jul.	Feb.	Jul.
Kelly Basin 1	Kelly Basin West	18.5	8.4	32.8	27.7
Kelly Basin 2	Kelly Basin South	19.0	9.5	32.8	29.2
Kelly Basin 3	Kelly Basin East	24.3	10.1	32.7	29.0
Kelly Basin 4	Bond Bay West	-	11.7	-	33.0
Kelly Basin 5	Kelly Basin Entrance	18.5	10.9	33.8	31.9
Hannant Inlet 1	Spain Bay	18.4	11.8	33.5	30.9
Hannant Inlet 2	Hannant Inlet Entrance	19.5	11.7	33.0	30.5
Hannant Inlet 3	Hannant Inlet South	24.0	11.6	32.3	29.8
Hannant Inlet 4	Hannant Inlet East	19.7	11.9	33.0	31.4
West Bathurst Channel 1	Bramble Cove North	20.2	12.2	32.6	32.4
West Bathurst Channel 2	Bramble Cove West	24.0	12.5	30.0	31.5
West Bathurst Channel 3	Beabey Cove	19.7	11.4	31.7	23.5
West Bathurst Channel 4	Schooner Cove West	19.5	11.0	31.7	23.2
West Bathurst Channel 5	Schooner Cove East	20.6	11.1	31.6	23.1
East Bathurst Channel 1	Horseshoe Inlet Entrance West	21.8	11.8	30.2	20.8
East Bathurst Channel 2	Horseshoe Inlet Entrance East	21.6	11.0	31.5	22.8
East Bathurst Channel 3	Balmoral Beach	20.0	11.5	31.3	22.3
East Bathurst Channel 4	Mt Rugby Beach	18.6	9.3	29.8	17.5
East Bathurst Channel 5	Platypus Point	18.6	9.5	30.1	17.3
Bathurst Harbour 1	Forest Lag	20.1	8.8	28.9	7.3
Bathurst Harbour 2	Bathurst Harbour South	20.0	9.4	28.3	12.2
Bathurst Harbour 3	Moulters Cove Entrance	20.0	9.4	28.1	10.7
Bathurst Harbour 4	Moulters Cove East	20.6	9.1	29.5	9.9
Bathurst Harbour 5	Bathurst Harbour West	20.5	9.5	26.1	10.0

exceptions: Eastern Bathurst Channel in October (2 replicates only), December (3 reps) and May (2 reps); Bathurst Harbour in October (2 reps); Melaleuca Inlet in May (2 reps); and the Old River (not sampled in February, May or July). The Bathurst Harbour site was separated into northern and southern sections; two nets were placed in each section except during October when the southern section only was sampled.

Because a single species, the white-spotted dogfish (*Squalus acanthias*), dominated the catches at all sites and was clearly a key component of the Bathurst Harbour ecosystem, some basic biological research was conducted on the local population of this species. A total of 105 individuals from five sites were tagged by placing yellow Roto tags in the baso-distal section of the dorsal fin, and their fork length and sex recorded. Whenever tagged individuals were recaptured their length was remeasured and locality recorded. The size-frequency distribution of *S. acanthias* within the estuary was determined during the July 1989 field trip by measuring the length and determining the sex of all captured dogfish.

Statistical analysis

Sites were classified by calculating a similarity matrix between pairs of sites using the Pearson correlation coefficient. The information in the similarity matrix has been heirarchically grouped using average linkage and presented as a dendrogram. A corresponding inverse analysis for fishes using the same data set was also made.

Results

A total of 29 fish species was collected by beach seine from the Bathurst Harbour estuary and Kelly Basin (table 5.2). Slightly more species were collected during the February survey (26) than during July (23), even though one more site was sampled on the latter occasion.

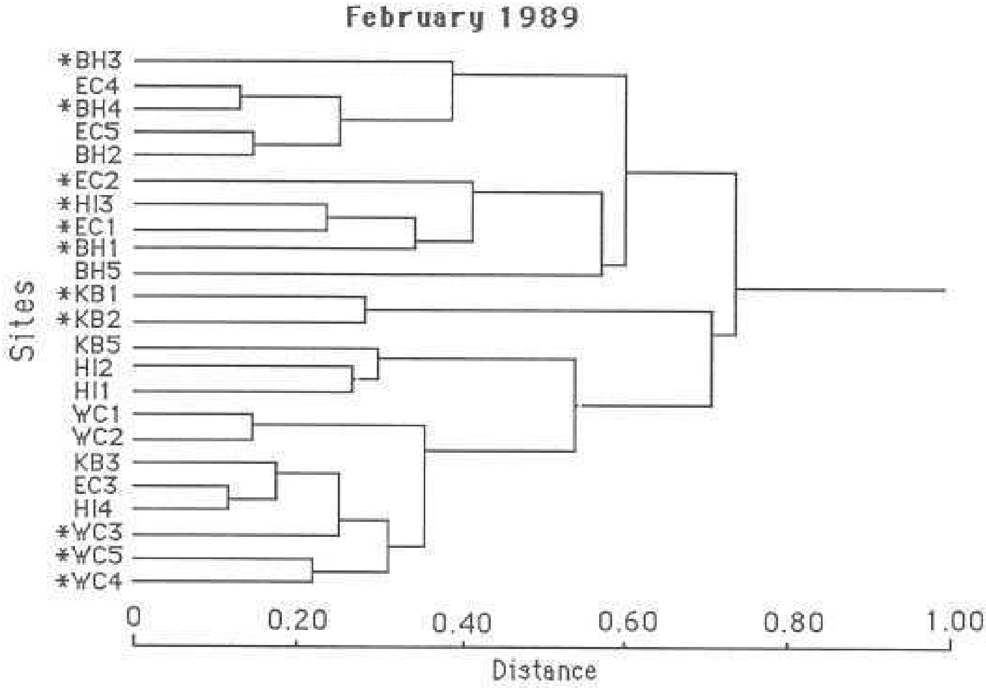
Three major groupings of sites are apparent when sites are classified by their February fish faunas (fig. 5.2). The two sheltered Kelly Basin sites (KB1 and KB2) were quite different to other sites. These sites both contained relatively diverse assemblages of fishes associated with seagrass beds. The other major division between sites was between locations east and west of the centre of Bathurst Channel; the only two exceptions to this major dichotomy were that Balmoral Beach (EC3), an exposed sandy beach in eastern Bathurst Channel, grouped with western Bathurst Channel sites, and the Hannant Inlet South site (HI3) grouped with eastern Bathurst Channel sites.

Table 5.2. Mean abundances of fish species collected by seine net during December, February and July field trips. Abundances are recorded on a log 3 abundance scale (i.e. 1 indicates 1 individual, 2 indicates 2-3 individuals, 3 indicates 4-9 individuals, etc.). Blank spaces indicate no fish were collected, dashes that no sample was made. Site locations are shown in fig. 5.1. *The two *Nesogobius* species were difficult to distinguish at some sites, particularly when small, so it is possible that some specimens may have been assigned to the wrong species.

Species	Month	Kelly Basin					Hannant Inlet				Bathurst Channel West					Bathurst Channel East					Bathurst Harbour				
		1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Raja lemprieri	Feb				-								1	1											
Retropinna tasmanica	Dec	-	-			-	-						-	-						3			3		
	Feb				-								1						1	1	1		4	2	
	July																		1		1	3	3	3	2
Lovettia sealii	Feb				-																				1
	July								1																
Galaxias maculatus	Dec	-	-			-	-			1			-	-							3	1	3		
	Feb				-					2			3		2	1			3		4			2	
	July															1					1	4	1		1
Hyporhamphus melanochir	Dec	-	-	1		-	-						-	-											
Atherinasoma microstoma	Dec	-	-	4	3	-	-	1	6				-	-		7	6			3	4		3	4	
	Feb		3		-				7	2				1		7	5		4	4	4	2		4	5
	July	9			2										2		3			3		3		1	5
Kestatherina brevirostris	Dec	-	-	1		-	-	-					-	-											
	Feb	2			-																				
	July	2	2											3											
Leptatherina presbyteroides	Dec	-	-	5	6	-	-		4				-	-					2	7			6		
	Feb	5	6	7	-	8	6	5		5	4	7	6	7	6			6	4	5		4	4	5	3
	July	1	4	8	5	8	5	4	7	7			3	6	7	4	8	5	6	6	6	1		4	2
Hippocampus abdominalis	Dec	-	-			-	-						-	-					1	1					
	Feb				-												1			1					
	July																			1					
Mitotichthys semistriatus	Feb				-										1										
Stigmatopora argus	Dec	-	-			-	-		1				-	-											
	Feb										1			1	1					1		1		1	
Gymnapistes marmoratus	Feb	5	6														4		1						
	July	5	2																1						
Platycephalus bassensis	Feb		1		-																				

Table 5.2. (Cont.)

Species	Month	Kelly Basin					Hannant Inlet				Bathurst Channel West					Bathurst Channel East					Bathurst Harbour				
		1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Arripis trutta	Dec	-	-	3	1	-	-	4			5	5	-	-	5										
	Feb		1	2	-	1	2				3														
	July			1		2	3	5		4	3	1		2	1			1							
Aldrichetta forsteri	Dec	-	-	2		-	-	2		5		6	-	-						1					
	Feb	2		3	-	2	2				3	3													
	July				6	2	4	1		4	3	1		3				3		5					
Neoodax balteatus	Feb	5	6										1	5	1	1	5		1	2		4			
	July	5	3													1	3								
Leseurina sp.	Dec	-	-		1	-	-	3					-	-											
	Feb				-		2	3																	
	July						1	3																	
Pseudophritis urvillii	Dec	-	-			-	-						-	-		2	2		3	2	3	2			1
	Feb	3	1		-				3					2		2	3		3	3	4	3	1	2	4
	July	3	3																		3			1	2
Cristiceps australis	Feb		2	1					1	1				2	2		2			1					
	July								1																
Heteroclinus perspicillatus	Feb	1	1		-																				
	July	1							1																
*Nesogobius hindsbyi**	Dec	-	-	4		-	-						-	-	3	4	4		3						
	Feb	4	5	5									6	4	4	4	4	4	3	2				2	
	July	2	3	4									4	3	2				2	2		1			1
Nesogobius sp.1*	Dec		-	-		-	-		5	3	2		-	-											
	Feb				-				3	3	2														
	July					3			1		1				3	2	2		2						
Ammotretis liturata	Dec	-	-	3	2	-	-				1		-	-											
	Feb			1	-		2	4				1													
Ammotretis rostratus	Dec	-	-			-	-			4		3	-	-				1							
	Feb			4	-		2			4	2	5	2					2							5
	July			2	1	3	1			3		4													1
Rhombosolea tapirina	Dec	-	-	3		-	-			3		3	-	-		1					1				1
	Feb	2		3					1		1	2												1	3
	July			1		3	1			3		1	1					1							
Acanthaluteres	Feb		5							1					3		3		2	4	2	4	4	3	
spilomelanurus	July	3	3																						
Contusus brevicaudus	July						1																		
Contusus richei	July						1				3	1													
Torquigener glaber	Dec	-	-	2		-	-					1	-	-	1	1	2		2	1				7	
	Feb	2	1	4	-		3		1	3	8	8	5	5	7	7	6	4	3	3	5	3	3	4	3
	July	1		5		1	3	2	1	2	2	4	4	1	2	2	2	3	1	3		3	1	1	2



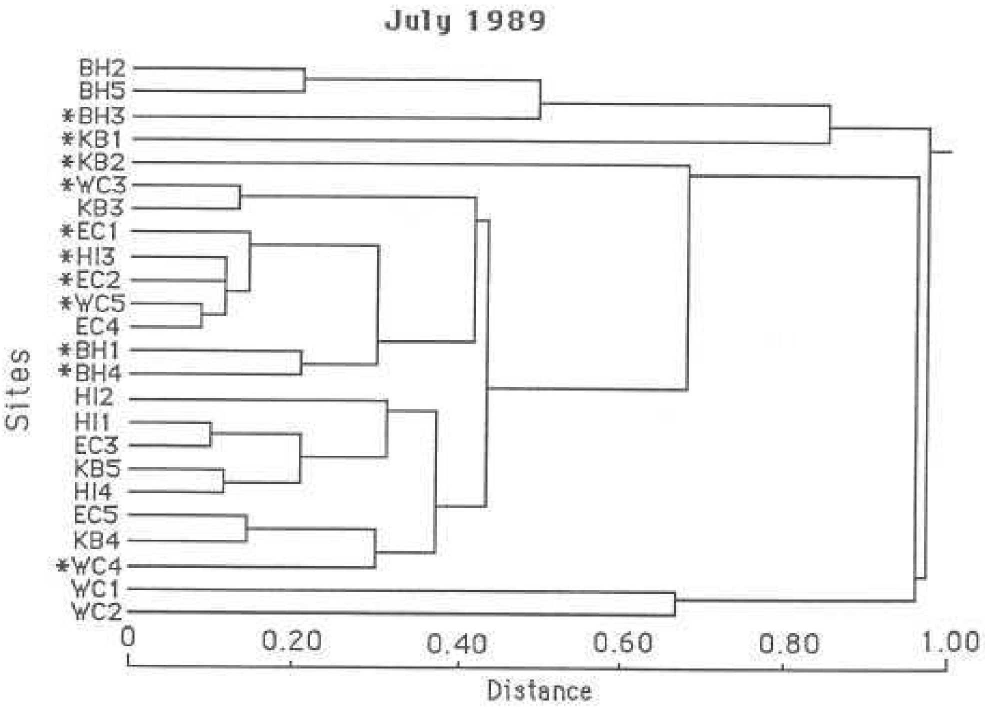


Fig. 5.2. Classification of sites using beach seine data. Sites are listed by area (Kelly Basin, KB; Hannant Inlet, HI; West Bathurst Channel, WC; East Bathurst Channel, EC; Bathurst Harbour, BH) and site number (fig. 5.1). * indicates that site has fine-sediment substratum.

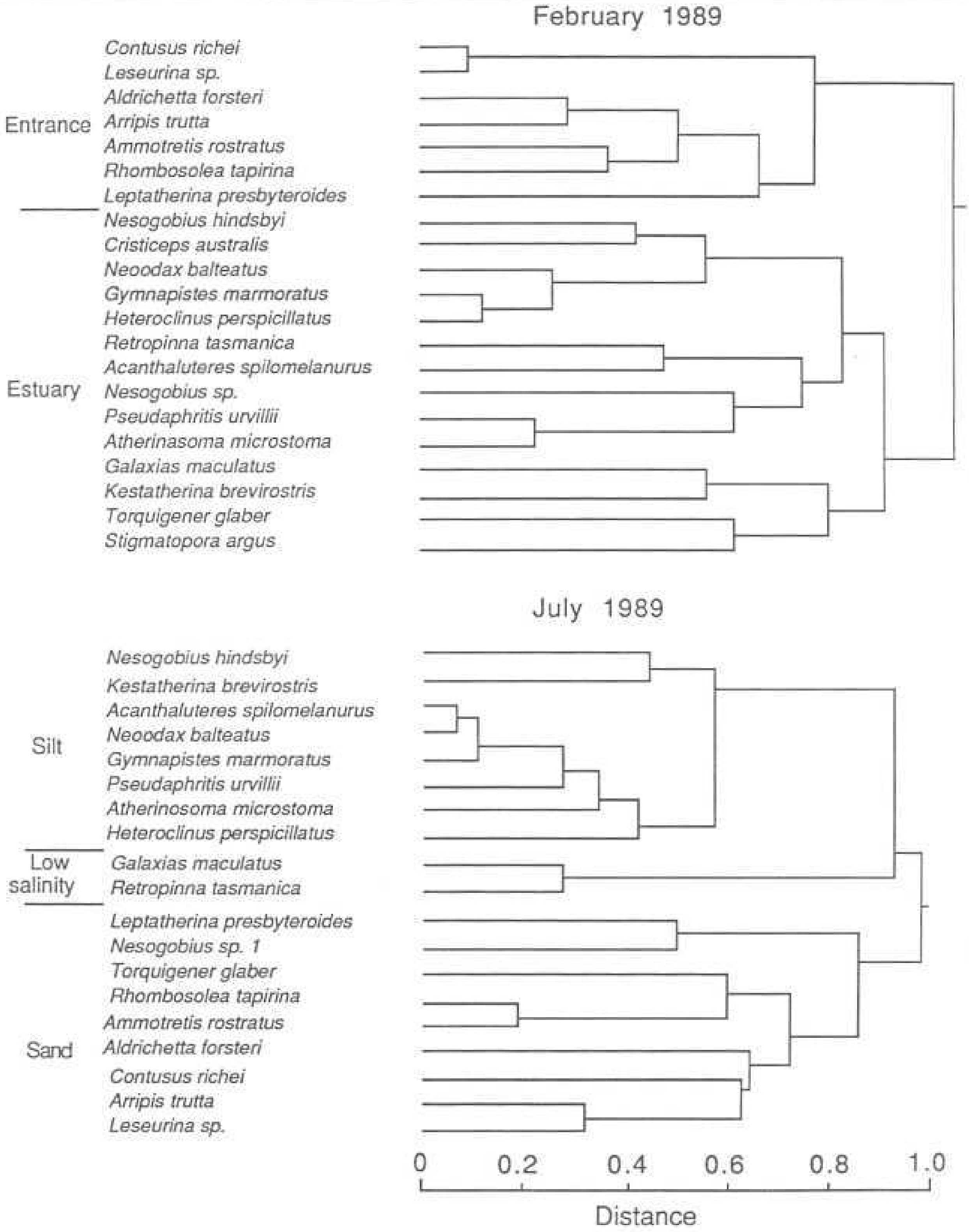


Fig. 5.3. Inverse classification of February and July beach seine data.

During July, sites separated much more on the physical characteristics of the site rather than on geographic position. Separate major groupings occurred between sites with fine sediment (silt and clay) and sites with coarse sediment (pebbles and sand) within the estuary (fig. 5.2). The Kelly Basin sites again showed little similarity with other sites, as did three of the Bathurst Harbour sites and the Bramble Cove sites in Bathurst Channel.

The inverse classification of the February and July data sets showed analagous patterns to the site classification (fig. 5.3). During February, the two major groups of fishes were those associated with sites adjacent to Port Davey and those associated with sites further up the estuary, while in July habitat type was much more important. The three major groups of fishes in July included a fine sediment and seagrass associated group, a coarse sediment group, and a group found only in the upper areas of the estuary. The latter group contained only two species (*Galaxias maculatus* and *Retropinna tasmanica*). The coarse sediment group was the least homogeneous, with marine-influenced species (*Aldrichetta forsteri, Contusus richei, Arripis trutta* and *Leseurina* sp.) linking to more estuarine species at a relatively low level of similarity (fig. 5.3).

The diversity of fishes collected by beach seine was related to both the salinity and substratum type of the habitat. The number of species collected from sites with soft sediments decreased up the estuary, while the opposite trend was found at sites with coarse sediments. This is depicted in fig. 5.4 where the total number of fishes collected at each site is plotted against the winter (July) salinity. The difference between these two regressions was found to be highly significant ($P<0.01$) using Analysis of Covariance (table 5.3). Note that although salinity and substratum type were related to fish diversity in this analysis, the analysis does not indicate that either of these factors were directly responsible for fish distribution patterns. Other physical factors were strongly correlated with salinity and substratum type, for example wave exposure was correlated with sediment type and nitrate levels with surface salinity, so the effects of particular physical factors could not be separated.

Gillnetting

Fishes collected during the gillnetting survey are listed in table 5.4. Almost all of these species are widely distributed around Tasmania. The only surprising catch was a previously unknown species of skate collected from the centre of Bathurst Harbour. Only three specimens of this fish were caught during the study, two of them being retained and lodged at CSIRO, Division of Fisheries. The species shows closest similarity to the New Zealand skate *Raja nasuta*, but reaches maturity at a much smaller size (P.R. Last, pers. comm.).

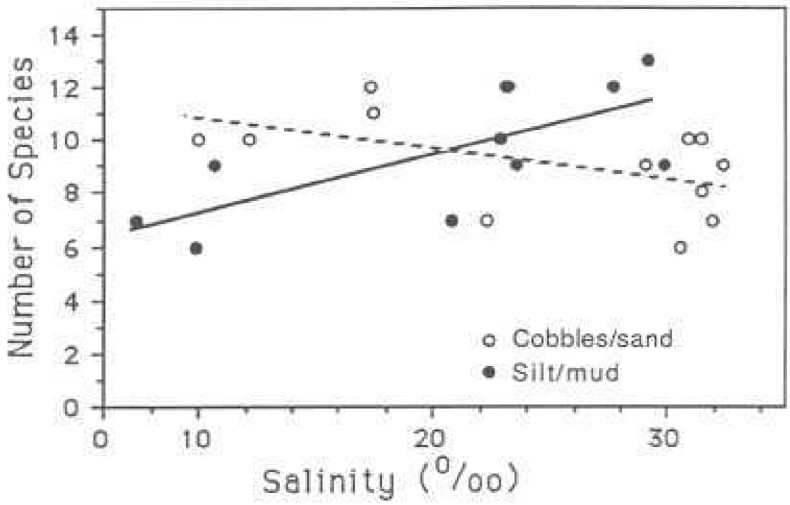


Fig. 5.4. The relationships between the number of fishes collected by beach seine at different sites and the winter(July 1989) salinity at those sites for two different habitat types: coarse-sediment (cobbles/sand) and fine-sediment (silt/mud) substrata.

Table 5.3. Results of Analysis of Covariance comparing the regressions relating total number of fish species collected by seining at a site and the winter (July 1989) salinity of the site for coarse sediment (cobbles/sand) and fine sediment (silt/mud) habitats.

Effect	d.f.	MS	F	P
Substrate	1	25.44	8.80	0.008
Salinity	1	3.47	1.20	0.287
Substrate x Salinity	1	35.05	12.12	0.002
Error	19	2.89		

Table 5.3. Number of fishes collected in gillnets set at different sites.

	Old River	Melaleuca Inlet	Bathurst Harbour	Celery Top I.	Platypus Pt	Bathurst Narrows	Channel Entrance	Total
Number of nettings	8	18	18	20	15	20	20	119
Species								
Heterodontus portusjacksoni	0	0	0	0	0	1	0	1
Notorhyncus cepedianus	0	0	0	0	0	0	3	3
Cephaloscyllium laticeps	0	0	0	0	0	0	2	2
Galeorhinus australis	0	0	0	0	1	1	1	3
Mustelus antarcticus	0	0	3	14	19	24	6	66
Squalus acanthias	0	0	687	190	149	316	89	1431
Raja lemprieri	0	0	0	0	1	0	0	1
Raja whitleyi	0	0	0	1	0	0	0	2
Raja sp.	0	0	3	0	0	0	0	3
Callorhynchus millii	0	0	3	13	24	5	1	46
Anguilla australis	0	1	0	0	0	0	0	1
Pseudophycis bachus	0	4	4	9	8	11	4	40
Pseudophycis barbatus	0	0	0	0	0	0	1	1
Cyttus australis	0	0	0	0	0	0	3	3
Hippocampus abdominalis	1	0	0	0	0	0	0	1
Stigmatopora argus	0	0	0	1	0	1	0	2
Neosebastes scorpaenoides	0	0	0	2	2	2	9	15
Cheilidonichthys kumu	1	2	0	7	3	0	0	13
Platycephalus bassensis	0	0	0	1	2	3	0	6
Pentaceropsis recurvirostris	0	0	0	0	0	0	1	1
Nemadactylus macropterus	0	0	0	2	0	0	0	2
Latridopsis forsteri	0	0	0	0	0	8	8	16
Notolabrus fucicola	0	0	0	0	0	2	1	3
Number of Species	2	3	5	10	9	11	14	23

Sharks and rays dominated the fish assemblage in the Bathurst Harbour estuary. The ten elasmobranch species collected by gillnet included the three most common fishes and also 95% of total fish numbers. The white-spotted dogfish *Squalus acanthias* was by far the most abundant species in the area, comprising 86% of the total catch. Teleosts were most common at the western entrance to Bathurst Channel, however even at this site they were less abundant than sharks.

Very few fish were collected in areas with considerable freshwater input, i.e. the Old River and Melaleuca Inlet. Eels were possibly the dominant fish in these areas, but could not be captured using gillnets, apart from one unlucky individual. Few species were also found in the centre of Bathurst Harbour, probably because of the lack of rocky substrata in the area. The abundance of dogfish in this area was, however, extremely high.

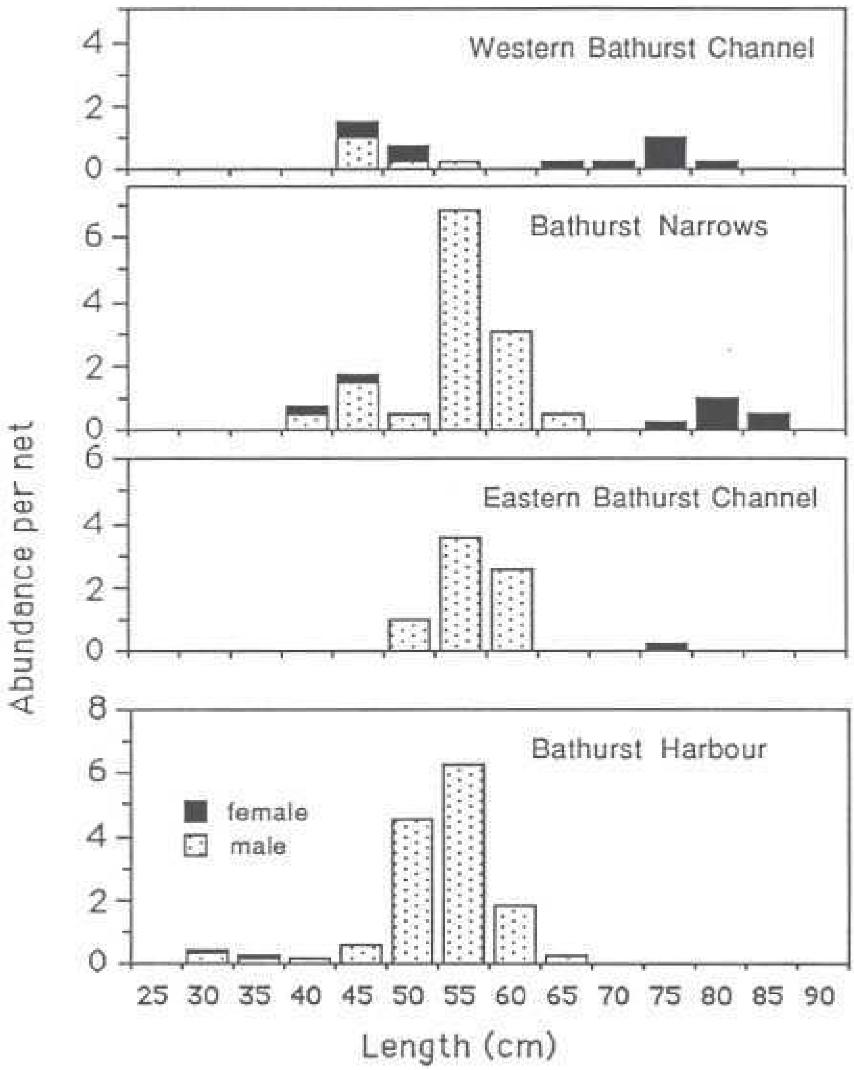
The population structure of *Squalus acanthias* differed markedly between different sites in the estuary (fig. 5.5). Large females and immature juveniles were collected at the Port Davey entrance to Bathurst Channel in July 1989, with mature males and a few small juveniles being found in Bathurst Harbour. The central area of Bathurst Channel was an overlap area in which the two groups of animals coexisted. These size-distribution patterns did not, however, remain constant throughout the year as no large females were collected in February. Most of the large females were pregnant, one of them releasing four young into the boat at Bathurst Narrows in November. The Bathurst Harbour estuary may be used for mating as well as spawning. Almost all large males were mature, releasing sperm on capture.

An extremely high proportion of tagged dogfish were recaptured. Of the total of 108 tagged animals, 28 (26%) were recaptured (table 5.5). Most of the recaptured animals were taken at sites well away from their release points, in two cases at the other end of the estuary (fig. 5.6). No obvious patterns were evident in the movement of animals, dogfish from any site having approximately equal probability of being recaptured at any other site in the area (fig. 5.6).

A small number (11) of gummy shark, *Mustelus antarcticus*, were also tagged and released during the study in Bathurst Channel. Two of these sharks were recaptured two months after release near where they were tagged, at Platypus Point and Gull Islet at the eastern end of Bathurst Channel.

Table 5.5. Numbers of *Squalus acanthias* captured, tagged and recaptured during the February, May and July 1989 gillnet surveys. The number of surviving tagged animals is the number of tagged animals released less the number of tagged animals which had previously died on recapture. Another tagged dogfish which is not listed here was released in December and recaptured in Hannant Inlet by a visiting yachtsman in February. *Two fish were collected in February and another in May with their dorsal fins hole punched and torn. These fish had lost their tags and are included in the total.

	Feb.	May	Jul.
Number of captured animals	198	291	346
Number of tagged animals recaptured	8*	10*	7
Number of tagged animals previously released	65	101	108
Number of surviving tagged animals	64	92	92



g. 5.4. Number of white-spotted dogfish in different size-classes collected in different areas of the Bathurst Harbour estuary in July 1989. The Celery Top Island and Bathurst Harbour data have been combined in this figure.

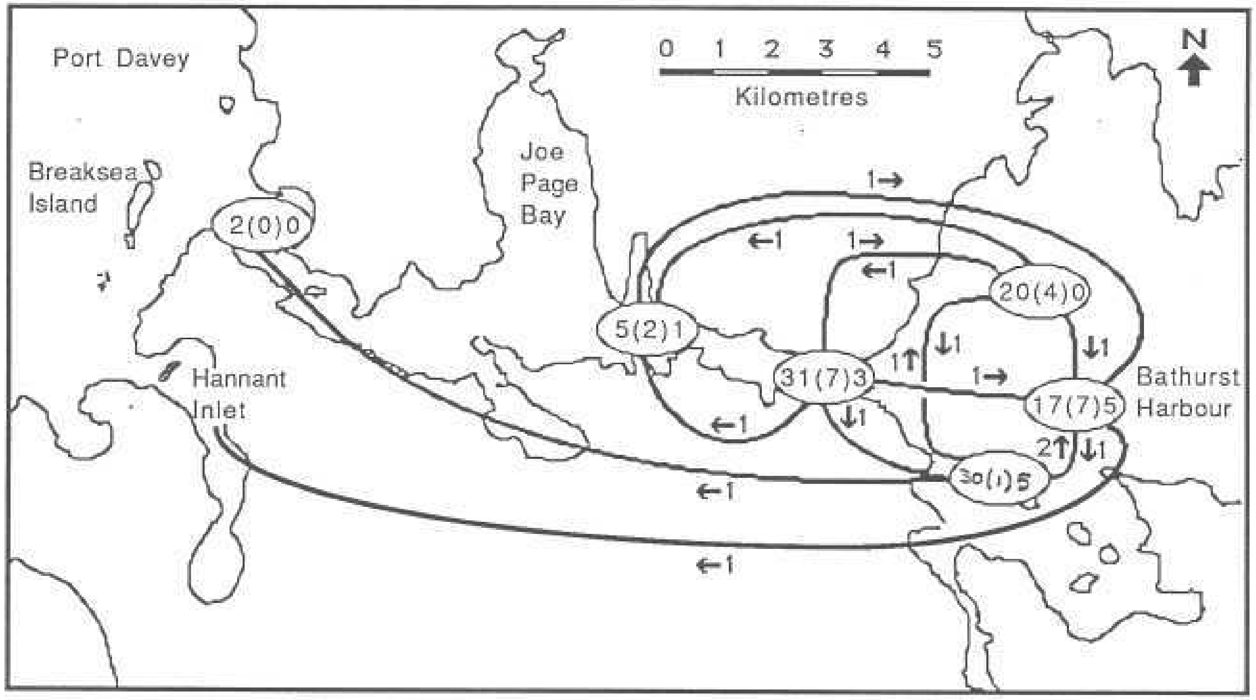


Fig. 5.5. Movement of tagged white-spotted dogfish in the Bathurst Harbour estuary. For each site the total number of dogfish released at that site is initially shown (followed by the number which were tagged at that site and later recaptured) followed by the number recaptured at the same site.

Discussion

The two methods of fish sampling, beach seining and gillnetting, yielded completely different faunas. Only four species, thornback skate *Raja lemprieri*, sand flathead *Platycephalus bassensis*, spotted pipefish *Stigmatopora argus* and wide-bellied seahorse *Hippocampus abdominalis*, were collected using both methods. Because no prior gillnetting study had been done in the Bathurst Harbour estuary, many of the fishes collected using this technique were new to the area (10 species). Beach seining provided seven additions to the previous list of fishes for the Port Davey region (Edgar 1984a). The only notable new record collected by seine was the Tasmanian whitebait, *Lovettia sealii,* a species which has been commercially overexploited elsewhere in Tasmania. Even though only two specimens of *L. sealii* were collected during the study, this fish may occur in high population densities in Bathurst Harbour because its open water habitat was not adequately sampled and specimens could easily pass through the 12 mm net mesh.

The other notable species collected during the study was the new species of skate (*Raja* sp.) taken in Bathurst Harbour. It is presently impossible to know whether this skate is restricted to the estuary or more widely distributed. If the skate is restricted to Bathurst Harbour then it has an extremely unusual and localised distribution; no other skate is known which is similarly restricted to a coastal embayment.

The entire Bathurst Harbour/Bathurst Channel assemblage of larger fishes was unusual in being dominated by species which are also commonly found in the deeper waters (>50 m) of the continental shelf. Gillnet samples were dominated, both in species and population numbers, by elasmobrachs. Sharks and rays generally increase in abundance and species richness offshore (Last & Harris 1981). *Squalus acanthias*, the most abundant species in Bathurst Harbour, has been found below 700 m (Hart 1973). The three common teleosts collected by gillnet, red gurnard *Cheilidonichthys kumu* , gurnard perch *Neosebastes scorpaenoides* and red cod *Pseudophycis bachus,* have also all been commonly recorded on the continental shelf below 50 m depth (Last & Harris 1981).

Low oxygen concentrations within the estuary during summer probably greatly affected the distribution of fishes, preventing a number of species from entering the estuary and causing the beach seined sites to group on a geographic Port Davey/Bathurst Harbour basis rather than a habitat basis (fig. 5.2). The recorded oxygen levels were certainly lower than salmonids can withstand for long periods (=150 μM, Alabaster & Lloyd 1982), presumably a major reason for trout not being recorded from the area. It is notable that all of the large active teleosts collected by beach seine and gillnet (i.e. the Australian salmon *Arripis trutta*, yellow-eye mullet *Aldrichetta forsteri*, bastard trumpeter *Latridopsis forsteri*, morwong *Nemadactylus macropterus* and purple wrasse *Notolabrus fucicola*) were not taken past Bramble Cove in summer but were found through Bathurst Channel in other seasons (table 5.1, appendix 4). Salinity is clearly not the primary environmental factor affecting species distribution in the area or the opposite trends would have been found, with marine species penetrating up the estuary in greatest numbers in summer.

The general decrease in the number of fish species collected by beach seine from sandy habitats as one moves toward the sea (fig. 5.4) was unexpected as it is contrary to the trends for fine-sediment associated fishes (fig. 5.4), gillnetted fishes (table 5.4), and planktonic (Chapter 4) and benthic taxa (Chapter 3). Perhaps this increase was trophically related; in contrast to fishes in silt habitats, most of the fishes collected from sand and cobbles were planktivorous open water fishes and the abundances of planktonic prey increased greatly up the estuary (Chapter 4). Species associated with fine-sediment habitats probably decreased up the estuary because dense seagrass beds occurred on silt sediments only in marine areas, with seagrasses becoming quite sparse in less saline waters. A component of fish species was commonly found only in association with seagrasses (e.g. *Gymnapistes marmoratus, Neoodax balteatus*).

The life history of the white-spotted dogfish, *Squalus acanthias*, is probably better known than any other shark. The species has been intensively studied because of its commercial importance and wide distribution around the world. Most of the information pertaining to the biology of this species has been summarised by Compagno (1984), who reports that:

(i) *S. acanthias* cannot survive freshwater for more than a few hours but tolerates brackish water,

(ii) it is a slow-growing species which is very long lived,

(iii) the species occurs in schools which are segregated by sex,

(iv) only males and large pregnant females generally occur in shallow water,

(v) pregnant females congregate in enclosed shallow bays where they release 1 to 20 young, and

(vi) the species prefers water between 7°C and 15°C, making latitududinal and depth migrations to stay within the optimal range.

In all respects this information agrees with observations made during the present study:

(i) *S. acanthias* was not collected in Melaleuca Inlet or the Old River but was widespread in the more marine sections of the estuary,

(ii) tagged individuals were slow growing, with many tagged animals not increasing in length while liberated and the fastest-growing animal increasing only 20 mm in 8 months,

(iii) large numbers of fishes were collected in small sections of gillnet, indicating a schooling habit, and there was also a clear size separation of stocks within the estuary (fig. 5.5),

(iv) intermediate-sized (55-65 cm) females were not collected,

(V) large pregnant females were found along Bathurst Channel between July and November, including one animal which released 4 young when brought into the boat,

(vi) numbers of captured animals were lowest during the summer survey, the period when water temperatures fell outside the preferred 7-15 °C range.

Although the very high numbers of dogfish captured in Bathurst Harbour suggests that an extremely large population exists in the area, the high proportion of tagged animals which were recaptured belies this. *Squalus acanthias* are slow swimmers which keep a regular pace in their nomadic movements (Compagno 1984). They wandered throughout the estuary rather than remained in localised populations (fig. 5.6). It therefore appears that the high capture rates ha[illegible] as much to do with their behaviour as with population densities. During each night an individual dogfish probably travels several kilometres, and thus has an appreciable probability of encountering a set net. In the February, May and July surveys ≈10% of previously tagged fish were recaptured. As 198, 291 and 346 dogfish were captured during these surveys, the local dogfish population is probably in the order of 2,500 animals. This may, however, be an overestimate because it does not take into account any handling or tag induced mortality of released animals, and this could well have been considerable. The dogfish population is clearly low enough for the netting program to have had the undesirable side-effect of significantly reducing local population numbers. While dogfish were released alive whenever possible, ≈50% of captured animals were dead before they could be released.

Chapter 6: **General Conclusions and Management Implications**

General Conclusions

At the commencement of the study it was felt that this investigation should have some value to others working on estuaries elsewhere in Australia because the results would provide unique baseline information on the state of an unexploited estuary. It now seems clear, however, that the Bathurst Harbour estuary is so different from any other that the data obtained cannot be readily compared with other sites. The only other estuaries with much in common with the Bathurst Harbour estuary are possibly the embayments along the west coast of the South Island of New Zealand.

A number of similarities are evident between the patterns of distribution of phytoplankton, zooplankton, benthic plants and animals and fishes in the Bathurst Harbour ecosystem. The various biotic groups all rapidly increase in diversity from the eastern to the western sections of Bathurst Channel and, with the exception of benthic plants, decrease in biomass in the same direction. These biotic groups also all separate on a geographic basis into marine groups near Sarah and Breaksea Islands, and estuarine groups distributed from central Bathurst Channel to Bathurst Harbour. Depending on the taxonomic group, the assemblage in Bathurst Channel may be quite different from the assemblage in Bathurst Harbour (benthic animals) or it may represent a transitional biota which is dominated by Bathurst Harbour species but also contains some marine Port Davey elements. The major characteristics of these various regions are summarised in table 6.1.

The boundary between marine-influenced Port Davey assemblages and Bathurst Harbour estuarine assemblages was well-defined, with only a slight change in position with season. The overlap zone between the marine and estuarine ecosystems can be generally defined as the small area between Sarah Island and Hammond Point on the north shore, and Forrester Point and Turnbull Head on the south shore of Bathurst Channel. This boundary is presumably a direct consequence of local water circulation patterns; west of the boundary waters probably receive regular mixing with the marine waters of Port Davey while east of the boundary estuarine water moves in and out with the tide but receives little mixing. All investigated physicochemical parameters change rapidly in this area (figures 2.2, 2.3 and 2.4). This boundary also approximately corresponds with the location at which the floor of the estuary changes from sand to mud.

Table 6.1. General characteristics of different regions of the Bathurst Harbour estuary.

	Bathurst Harbour	Bathurst Channel	Port Davey
Surface salinity in winter	Low	Medium	High
Summer oxygen level	Low	Low	?High
Surface nitrate level	Extremely low	Low	Moderate
Dominant phytoplankton	Dinoflagellates	Dinoflagellates	Diatoms
Zooplankton biomass	High	High	Low
Zooplankton diversity	Extremely low	Low	Moderate
Benthic plant diversity	Extremely low	Low	High
Major infralittoral plant	*Hormosira banksii*	*Hormosira banksii*	*Durvillaea antarctica*
Benthic animal diversity	Extremely low	Low	High
Mobile epifaunal diversity	Low	Moderate	Very High
Major mobile invertebrates	*Paramoera* sp. *Eusirid* sp. *Paracorophium excavatum* *Tatea rufilabrus*	*Parawaldeckia yamba* *Aora maculata*	*Hyale ?kandari* *Mallacoota carteta* *Mallacoota diemenensis* *Pisinna circumlabra*
Major fishes collected by beach seine	*Aldrichetta forsteri* *Arripis trutta* *Leptatherina presbyteroides* *Leseurina* sp. *Ammotretis rostratus* *Torquigener glaber*	*Atherinasoma microstoma* *Leptatherina presbyteroides* *Pseudophritis bursinus* *Nesogobius hindsbyi* *Neoodax balteatus* *Torquigener glaber*	*Galaxias maculatus* *Retropinna tasmanica* *Atherinasoma microstoma* *Leptatherina presbyteroides* *Pseudophritis bursinus* *Torquigener glaber*

The planktonic and benthic communities in the Bathurst Harbour estuary did, however, differ in one major respect. Phytoplankton and zooplankton assemblages both appeared to directly linked with salinity, with the seasonal influx of high densities of taxa such as *Gyrodinium* sp., *Protoperidinium* sp., *Paracalanus indicus* and *Acartia sp.* into Bathurst Harbour during summer. Mobile invertebrates and fishes, on the other hand, were not greatly affected by seasonal changes in salinity. Dissolved oxygen levels were inferred to have a greater influence on the distribution of fishes.

Management Implications

Rare and Endemic Plants and Animals

The planktonic, benthic and fish assemblages in the Port Davey region all have relatively low numbers of species, so it is not surprising that few endemic or unusual taxa were recorded during the study. The most noteworthy species known from Port Davey and Bathurst Harbour are:

(i) the skate *Raja* sp. This species is known from only three records from the centre of Bathurst Harbour. The restricted range of this ray is extremely unusual for a marine fish; I know of no other large marine fish in Australia which has a similarly localized distribution. It is therefore possible that this species also occurs in deeper waters off the Tasmanian coast or Macquarie Harbour. Dr P. Last, a skate taxonomist at CSIRO Division of Fisheries, has suggested, however, that it is equally likely that the species survives as a relict population confined to Bathurst Harbour because extensive trawl surveys made around Tasmania during the past decade should have yielded the species if at all widespread. Moreover, all other Australian skates which occur in shallow water have been collected on numerous occasions. If *Raja* sp. is restricted to Bathurst Harbour then it is amongst the rarest of fish species. The population in Bathurst Harbour would be unlikely to exceed 2,000 animals.

(ii) the brotulid fish *Microbrotula* sp. which is only known from a specimen collected in a cave in Bathurst Channel near Schooner Cove.

(iii) the green alga *Caulerpa ?alternans*. *Caulerpa ?alternans* is the dominant plant in the western section of Kelly Basin, Port Davey, forming almost monospecific beds in the area. This species differs slightly in its branching pattern from the few known specimens of *Caulerpa alternans*, so it is difficult to presently determine whether or not it is a distinctive species. *Caulerpa alternans* itself is amongst the most poorly known of the Australian species of *Caulerpa*, having been collected from predominantly rock habitats in deep water at only Port Phillip Heads, Victoria, and Gulf St Vincent and Spencer Gulf, South Australia (Womersley, 1984). The deep-water, epilithic habitat of *C. alternans* is quite different from the shallow sedimentary habitat in which *C. ?alternans* occurs. It is unlikely that *C. alternans* forms dense beds in deep water, so even if the two taxa are conspecific, the monospecific beds of *C. ?alternans* probably provide a habitat which is unique to the area.

(iv) an undescribed gastropod which was collected as a single specimen from tanikalon clumps placed at 4 m depth off Breaksea Island during the survey. Mrs E. Turner, micromollusc taxonomist at the Tasmanian Museum and Art Gallery, could not classify this unusual mollusc into a family.

Equally as important as these rare species are two assemblages of organisms which are probably unique to the area.

The abundance and species composition of phytoplankton has been shown in numerous studies to be greatly influenced by the concentration and relative proportions of plant nutrients (Tilman 1977; Sanders *et al.* 1987; Doering *et al.* 1989), so given that the surface waters of Bathurst Harbour have extremely low levels of nutrients compared with other estuaries, it seems reasonable to assume that the planktonic community is unique. A more detailed study of the phytoplankton in Bathurst Harbour, including the nanoplankton and picoplankton, could well reveal taxa which are dependent on the low-nutrient conditions, being outcompeted in other estuaries.

The other unusual assemblage in the Bathurst Harbour estuary consisted of the larger fishes. This assemblage occurred in shallow water but had many of the characteristics of fish communities found on the continental shelf.

The Bathurst Harbour plankton and fish communities are important not just from a conservation perspective but also for their scientific value. The planktonic community is important because the low nutrient waters provide an ideal environment for small scale manipulative experiments using microcosms aimed at determining the impact of nutrients on planktonic communities. Such experiments can only be carried out in low nutrient environments because, while it is a relatively simple matter to add particular nutrients and monitor changes in planktonic populations, there is no practical way to selectively remove chemical compounds from the nutrient-rich water generally present in estuaries. The Bathurst Harbour plankton community has the added advantage that it has very few species, so interactions between species can be examined relatively easily. The benthic fish fauna of Bathurst Harbour has great scientific value because a normally deep water fauna is so accessible at that site; processes which generally occur in waters of the continental shelf below 50 m can be observed using normal SCUBA diving methods.

Because of their unique status and scientific value, the highest priority should be given to the preservation of the plankton and fish communities in Bathurst Harbour. In the case of the plankton community, this would entail preventing the discharge of large quantities of plant nutrients (e.g. sewage, fish foods) into the system. Preserving the Bathurst Harbour ecosystem has the added benefit of safegarding the habitat of *Raja* sp. Steps should also be taken to preserve the Kelly Basin habitat of *Caulerpa ?alternans*.

The Impact of Potential Future Developments in the Area

Tourist Developments

The impact of tourist developments on the plants and animals in the Bathurst Harbour estuary clearly depends on the scale of such developments. Small scale developments would be unlikely to greatly influence the estuarine biota, unless sewage is discharged directly into the system. Larger developments, however, would be inadvisable because of increased levels of rubbish and effluent, and also an increased possibility that exotic plankton or invertebrates may be inadvertently transported to the region by boats.

The bottom water in the Bathurst Harbour estuary was inferred in this study to have a long residence time. If any release of effluent into the estuary is to occur, the density of the effluent should be kept as low as possible, with the release made close to the water surface rather than near the estuary bed. This is particularly important in Melaleuca Inlet where dense bottom water remains trapped in the deeper holes for lengthy periods of time.

One additional impact of tourism in the Melaleuca area which should be considered is bank erosion along Melaleuca Inlet resulting from boat bow waves. The extent of bank erosion in the Inlet should be monitored, and boat speed limits introduced if erosion is found to be occurring.

Fish Farming

Salmonids: In contrast with Macquarie Harbour, the Port Davey region appears to be unsuitable for the caging of salmonids because of the high wave energy in Port Davey, the shallow water depths (<7 m) in Kelly Basin, Bond Bay, Bathurst Harbour and most of Bathurst Channel, and the low oxygen levels in the Bathurst Harbour estuary during summer. Fish farming in the Bathurst Harbour estuary which involves the addition of food to the environment should be proscribed in any case, as this would be expected to elevate nutrient levels in the system, and thus destroy the low nutrient status of the estuary.

Oysters: Kelly Basin appears to be a highly suitable area for oyster farming. I recommend, however, that this not be allowed because of the unique *Caulerpa ?alternans* habitat in the area. In particular I feel that the importation of pacific oysters, *Crassostrea gigas*, to Port Davey should be prevented. Pacific oysters were initially introduced into Tasmania in the mistaken belief that water temperatures in the state are so low that the oysters would be unable to reproduce and expand into natural habitats. With the recent increase in oceanic water temperatures around the state (Harris *et al.*, 1987), pacific oysters are becoming increasingly abundant around the shores of Tasmanian estuaries where they compete with native benthic invertebrates for space. For conservation reasons, it is worthwhile maintaining the isolation from *C. gigas* of this section of the Tasmanian coast.

Scallops: Considerable interest has been expressed in the reseeding and harvesting of scallops in the larger Tasmanian bays. There presently seems little reason to prevent the reseeding and exploitation of Port Davey scallop beds, providing that scallops are harvested by diver rather than dredge and that no shorebased processing is carried out.

Exploitation of local fishes

My fish survey illustrates dramatically the effect of gillnetting on local fish stocks. Although dogfish appear extremely abundant in the Bathurst Harbour estuary, the population was estimated to be only ≈2,500 fish. Each set of a gillnet in Bathurst Harbour caught an average of 38 dogfish, ≈1.5% of the total population. Because of the great effect a few gillnets have on fish populations, gillnetting should be banned in the Bathurst Harbour estuary and Port Davey.

Other

Hydro-electric dams or additional mining clearly have the potential to adversely affect the estuary. One effect of dams which has rarely, if ever, been addressed is the impact of nutrient rich waters on downstream estuarine ecosystems. Such effects would be expected to be particularly severe in the Bathurst Harbour region because of the low nutrient nature of the surface waters. The World Heritage status of Port Davey and its catchment area should, however, preclude any such development, apart from a possible increase in the existing level of mining in the Melaleuca/Cox Bight area.

The present tin mining activity in the Conservation Area at Melaleuca does not have any obvious effect on the flora or fauna of the Bathurst Harbour estuary, although it should be emphasized that the flora and invertebrate fauna of Melaleuca Inlet were not surveyed during the present study. Nutrients, suspended particulates and heavy metals in the runoff which enters Melaleuca Inlet from the mining leases should not be allowed to increase above the present low levels.

Desirable Future Work

Because of the short-term nature of the present study, which presents snapshots of the plant and animal distribution patterns in the Bathurst Harbour estuary, the investigation has raised more questions than answers. The major deficiency of the study is that it is not known whether the described patterns are one-off or are in fact representative of particular seasons. Additional data collected in future years is needed to enable the seasonal and interannual variability to be described. The study was also primarily restricted to the Bathurst Harbour estuary. Consequently, very little remains known about the hydrology, plankton and benthos of Port Davey, Bond Bay or Kelly Basin, or the lower reaches of rivers and streams.

From the viewpoint of interpreting the distribution patterns of plankton and benthos, the hydrological survey needs to be extended by determining the concentrations of silicates and phosphates in the estuary. Low levels of either of these plant nutrients would affect the distribution and growth of algae. The oxygen status of the estuary during summer also needs to be determined in much more detail, along with information on the hydrology and movement of waters in the biotic transitional area at the western end of Bathurst Channel, between Schooner Cove and Sarah Island.

Major deficiencies in the plankton study were the lack of data on the depth distribution of phytoplankton and zooplankton, the lack of production estimates, and the lack of information on the distribution of chlorophyll within the estuary. Moreover, the nanoplankton and picoplankton communities went unstudied, with these groups being inferred to provide a vital link in the food chain leading to copepods and fishes. The question of why dinoflagellate and zooplankton populations increase so dramatically up the estuary also remains unresolved.

Very little is yet known about the soft-sediment benthos in the Port Davey area; this component of the fauna was only cursorily examined in the present investigation. Some work should especially be done on the benthos in the western section of Port Davey to determine whether the brackish water layer descends to the estuary bed during periods of peak freshwater outflow, and its influence on the fauna at these times. A high priority should also be placed on a study of the fauna associated with the interesting *Caulerpa ?alternans* habitat in Kelly Basin.

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APPENDIX 1A (cont.). Water temperatures (^{o}C) in Melaleuca nlet on 12 October 1988.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	10.5	10.4	11.5	11.1	10.9
1	10.5	10.6	11.0	11.1	10.7
2	10.9	10.7	10.6	10.5	10.7
3	10.7	10.7	10.6		10.7
4			10.6		11.1
5					11.8
6					12.1
7					12.4
8					12.4
9					12.4

APPENDIX 1B. Water temperatures (^{o}C) at Bathurst Harbour and Bathurst Channel on 27 November 1989.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	15.8	15.9	16.4	17.1	16.4	15.8	15.5	15.6	14.9	15.5
1	15.6	15.8	15.7	15.8	16.0	14.5	14.7	14.7	14.8	
2	15.4	16.0	15.7	15.8	15.0	14.0	14.1	14.4	14.4	
3	14.6	14.5	14.5	14.6	14.2	13.9	13.9	14.2	14.0	
4	13.8	14.0	14.0	14.2	14.0	13.9	13.7	14.0	13.8	
5		13.9	14.0	14.0	14.0	13.9	13.7	13.9	13.6	
6		13.5	13.7	13.7	14.0	13.9	13.6	13.7	13.5	
7		13.5	13.5		14.0	13.7	13.5	13.8	13.4	
8					14.0	13.7	13.4	13.8	13.4	
9					14.0	13.7	13.4	13.6		
10					14.0	13.6	13.4	13.6		
12						13.6	13.4	13.6		
14						13.6	13.4	13.5		
16						13.6	13.4	13.5		
18						13.6	13.4	13.4		
20						13.5	13.4	13.4		
22						13.4	13.4			

APPENDIX 1B (cont.). Water temperatures (^{o}C) in Melaleuca Inlet on 2 December 1988.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	13.7	13.3	14.5	14.6	14.6
1	13.8	13.8	14.6	14.8	14.5
2	13.9	14.0	14.6	14.8	14.2
3	13.9	14.0	14.4		14.2
4		14.0	14.3		14.0
5		14.0			14.0

APPENDIX 1B (cont.). Water temperatures (^{o}C) in Old River on 27 November 1988.

Depth (m)	Mouth	First Bend	Huon Pines	Islet
0	15.8	12.5	12.2	11.5
1	15.6	12.3	11.5	11.4
2	15.4	15.2	15.2	
3	14.6		14.9	
4	13.8			

APPENDIX 1C. Water temperatures (^{o}C) at Bathurst Harbour and Bathurst Channel on 8 February 1989.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	21.6	23.9	24.2	[illegible]	22.0	20.1	20.4	19.9	18.2	19.8
1	20.2	20.6	20.3	20.5	20.8	18.8	19.6	19.4	16.7	19.4
2	20.0	19.9	19.7	19.8	20.4	17.5	18.6	18.9	16.5	19.2
3	19.2	19.8	19.4	19.5	19.7	17.4	17.8	17.8	16.5	17.6
4	17.7	18.0	17.6	19.3	18.8	16.5	17.1	17.5	16.1	17.0
5		17.6	17.4	18.3	17.5	16.4	16.5	17.0	15.5	16.2
6		17.4	17.2	17.2	17.1	16.2	16.2	16.5	15.3	15.7
7		17.2	17.1		16.9	16.2	15.6	16.5	15.3	15.4
8					16.6	15.5	15.4	16.5	14.8	15.2
9					16.5	15.1	15.0	16.0	14.7	15.1
10					16.2	15.1	14.8	15.6	14.5	15.0
12					16.0	15.0	14.6	15.2		14.6
14					15.9	14.9	14.5	15.0		14.4
16					15.6	14.9	14.2	14.5		14.1
18						14.6	14.2	14.4		14.0
20							14.1	14.4		14.0
22								14.1		

APPENDIX 1C (cont.). Water temperatures (^{o}C) in Melaleuca Inlet on 8 February 1989.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	20.8	20.6	20.8	21.2	20.6
1	20.6	20.3	20.0	19.8	20.2
2	20.3	20.1	19.5	19.5	19.7
3	20.2	20.0	18.5		19.4
4		19.9	17.9		19.0
5		19.8			18.2
6					16.7
7					16.5
8					16.2
9					16.1

APPENDIX 1C (cont.). Water temperatures (^{o}C) in Davey River on 8 February 1989.

Depth (m)	Carvers Pt Shoal	Settlement Pt	Foot Track Islet	Davey Gorge
0	17.0	16.9	16.1	15.8
1		16.8	16.1	
2		16.8	19.3	
3		16.7		
4				
5				

APPENDIX 1D. Water temperatures (^{o}C) at Bathurst Harbour and Bathurst Channel on 27 May 1989.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	8.6	8.5	8.2	8.6	8.0	11.4	11.7	11.0	12.4	12.5
1	9.8	10.0	9.7	9.5	8.2	11.4	11.9	11.4	12.8	13.6
2	11.0	11.0	11.1	11.2	11.0	12.1	12.0	12.4	13.1	13.7
3	11.8	11.6	11.5	11.7	12.1	12.5	12.8	12.8	13.1	13.9
4	12.0	12.6	11.9	12.4	12.7	13.0	13.0	12.8	13.7	14.0
5		13.2	13.0	12.5	12.8	13.0	13.1	13.0	14.0	14.1
6		13.4	13.0	12.8	12.8	13.0	13.5	13.2	14.1	14.1
7		14.0	13.3		12.9	13.0	13.6	13.4	14.1	
8					13.1	13.0	13.9	13.4	14.2	
9					13.1	13.0	13.9	13.4	14.4	
10					13.1	13.0	13.9	13.5	14.5	
12					13.3	13.1	14.0	13.5	14.5	
14						13.5	14.0	13.7		
16						13.8	14.0	13.7		
18						13.9	14.0	13.8		
20						13.9	14.1	14.0		
22						14.0	14.1	14.0		
24						14.0	14.1	14.0		
26						14.0	14.1	14.0		
28						14.0	14.1	14.0		
30						14.0	14.2			

APPENDIX 1D (cont.). Water temperatures (^{o}C) in Melaleuca Inlet on 27 May 1989.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	8.5	9.0	9.8	9.7	9.0
1	10.5	10.5	9.6	10.2	9.5
2	10.9	10.6	11.0	11.4	11.1
3	10.9	11.0	11.9		11.6
4		11.0	12.1		12.5
5					13.0
6					13.1
7					13.2
8					13.2
9					13.2

APPENDIX 1E. Water temperatures (^{o}C) at Bathurst Harbour and Bathurst Channel on 25 July 1989.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	8.5	8.4	8.0	8.2	7.9	9.0	9.7	9.8	11.3	12.0
1	8.0	8.3	8.5	8.9	8.0	9.8	10.1	10.3	11.5	12.0
2	10.3	10.3	10.4	10.4	11.5	11.8	11.3	11.7	11.5	12.3
3	11.3	11.6	11.5	11.7	12.1	11.8	11.7	12.0	11.5	12.3
4	11.9	12.2	12.0	12.0	12.1	11.8	12.0	12.1	12.1	12.3
5		12.2	12.1	12.1	12.1	12.0	12.0	12.3	12.4	12.3
6		12.4	12.1	12.2	12.2	12.1	12.1	12.4	12.7	
7		12.5	12.4		12.2	12.1	12.3	12.4	12.8	
8					12.2	12.3	12.5	12.4	12.8	
9					12.2	12.3	12.5	12.6	13.0	
10					12.2	12.5	12.5	12.6	13.0	
12					12.2	12.5	12.5	12.7		
14					12.2	12.5	12.7	12.9		
16					12.2	12.6	12.7	13.0		
18						12.6	12.7	13.0		
20						12.6	12.8	13.0		
22						12.6	12.9	13.0		
24						12.6	12.9	13.0		
26						12.6	12.9	13.0		
28						12.6	13.0	13.0		
30						12.6	13.0	13.0		

APPENDIX 1E (cont.). Water temperatures (^{O}C) in Melaleuca Inlet on 25 July 1989.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	8.2	8.2	8.2	8.2	8.0
1	9.0	8.2	8.1	8.6	8.3
2	9.7	10.1	10.4	10.8	10.9
3	9.9	10.2	11.5		12.1
4			11.7		12.1
5					12.1
6					12.3
7					12.3
8					12.3
9					12.3

APPENDIX 1E (cont.). Water temperatures (^{o}C) in Old River on 25 July 1989.

Depth (m)	Mouth	First Bend	Huon Pines	Islet
0	8.5	7.6	6.2	5.7
1	8.0	8.1	7.5	7.1
2	10.3	9.1	9.0	
3	11.3	9.7	9.5	
4	11.9			

APPENDIX 2A. Salinities ($^{o}/_{oo}$) at Bathurst Harbour and Bathurst Channel on 8 October 1988.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	6.1	8.3	9.9	10.3	11.0	12.1	13.7	14.5	18.2	28.9
1	6.8	8.5	9.9	10.3	11.1	12.8	13.7	15.5	20.9	
2	8.9	9.0	10.1	10.4	11.2	13.7	14.1	18.0	28.6	
3	9.2	11.3	10.2	11.2	12.4	17.5	15.8	32.0	33.1	
4	10.3	11.5	11.3	12.3	13.8	20.1	27.0	32.8	34.5	
5		12.9	11.9	13.3	15.4	27.1	30.2	32.9	34.8	
6		15.5	17.2	19.6	31.5	31.0	32.1	33.7	34.8	
7		27.5	27.4		32.8	32.2	33.8	34.0	34.8	
8					33.3	33.0	34.1	34.2		
9					33.8	33.5	34.3	34.3		
10					33.9	33.9	34.8	34.7		
12					34.0	3[illegible].4	34.9	35.1		
14					34.1	34.9	34.9	35.1		
16					34.2	35.0	34.9	35.1		
18						35.0	34.9			
20						35.0	34.9			
22						35.0	34.9			
24							34.9			
26							34.9			
28							34.9			
30							34.9			

APPENDIX 2A (cont.). Salinities ($^{o}/_{oo}$) in Melaleuca Inlet on 12 October 1988.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	0.1	0.4	1.5	5.0	7.5
1	0.2	0.6	3.8	5.4	8.3
2	0.6	5.5	9.1	9.2	9.1
3	11.2	11.5	11.2		9.4
4			11.6		15.9
5					29.4
6					32.2
7					33.7
8					33.7
9					33.7

APPENDIX 2B. Salinities ($^{o}/_{oo}$) at Bathurst Harbour and Bathurst Channel on 27 November 1988.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	14.6	14.7	12.6	14.5	15.6	20.1	26.6	28.2	32.1	33.4
1	16.1	15.4	15.3	15.6	16.4	28.5	27.6	30.2	32.5	
2	26.0	20.3	20.0	21.1	25.2	31.9	30.9	30.4	33.3	
3	29.3	30.5	29.9	30.6	31.3	32.9	32.7	31.6	33.6	
4	31.5	32.8	32.8	32.6	32.2	33.1	33.2	32.6	33.9	
5		33.2	33.1	32.9	32.7	33.1	33.6	32.9	34.7	
6		34.6	34.2	34.1	32.9	33.2	34.2	33.7	34.9	
7		34.7	34.7		32.9	33.6	34.8	34.0	35.0	
8					32.9	33.8	35.1	34.2	35.0	
9					32.9	33.8	35.2	34.2		
10					32.9	34.0	35.3	34.3		
12						34.2	35.3	34.6		
14						34.3	35.3	34.8		
16						34.4	35.3	34.9		
18						34.4	35.3	35.1		
20						34.5	35.2	35.4		
22						34.5	35.2			

APPENDIX 2B (cont.). Salinities ($^{o}/_{oo}$) in Melaleuca Inlet on 2 December 1988.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	16.2	13.7	19.9	20.3	20.0
1	16.9	16.3	20.0	20.7	23.3
2	17.0	16.8	20.1	29.5	30.4
3	17.0	16.8	30.8		31.3
4		16.8	31.4		31.4
5		16.8			31.4

APPENDIX 2B (cont.). Salinities ($^{o}/_{oo}$) in Old River on 27 November 1988.

Depth (m)	Mouth	First Bend	Huon Pines	Islet
0	14.6	0.9	0.6	0.1
1	16.1	3.4	0.8	0.4
2	26.0	16.3	16.3	1.2
3	29.3		24.9	
4	31.5			

APPENDIX 2C. Salinities ($^{o}/_{oo}$) at Bathurst Harbour and Bathurst Channel on 8 February 1989.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	28.3	28.4	28.6	28.0	29.2	29.7	32.2	32.4	33.2	34.1
1	28.9	28.8	28.9	28.7	29.3	31.2	32.4	32.5	34.1	34.1
2	29.1	28.9	29.2	29.0	29.3	31.9	32.2	32.7	34.1	34.0
3	30.1	29.3	29.8	29.5	29.4	32.4	32.6	33.0	34.1	34.2
4	32.2	31.6	32.2	30.1	30.5	33.2	33.4	33.3	34.3	34.4
5		32.7	32.3	32.6	32.4	33.4	33.6	33.4	34.7	34.6
6		33.1	32.8	33.0	32.6	33.5	33.9	33.8	34.9	34.7
7		33.1	32.9		33.1	33.5	34.3	33.9	34.9	34.9
8					33.3	33.8	34.7	33.9	35.0	34.9
9					33.4	34.6	35.0	34.2	35.1	35.0
10					33.7	34.6	35.0	34.4	35.3	35.0
12					33.8	34.7	35.0	34.8		35.2
14					34.0	34.8	35.1	34.9		35.2
16					34.1	34.8	35.1	35.1		35.3
18						34.9	35.2	35.2		35.3
20							35.2	35.2		35.3
22								35.3		

APPENDIX 2C (cont.). Salinities ($^{o}/_{oo}$) in Melaleuca Inlet on 8 February 1989.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	25.8	26.1	27.6	28.8	28.9
1	26.7	26.5	28.2	28.9	28.9
2	27.0	27.0	28.9	29.3	29.1
3	27.0	27.8	30.5		29.1
4		28.4	32.1		29.4
5					30.5
6					34.9
7					34.9
8					35.0
9					35.0

APPENDIX 2C (cont.). Salinities ($^{o}/_{oo}$) in Davey River on 8 February 1989.

Depth (m)	Carvers Pt Shoal	Settlement Pt	Foot Track Islet	Davey Gorge
0	34.5	7.2	0.0	0.0
1		15.1	2.0	0.0
2		29.7	32.6	0.0
3		30.6		0.0
4				0.0
5				0.0

APPENDIX 2D. Salinities ($^{o}/_{oo}$) at Bathurst Harbour and Bathurst Channel on 27 May 1989.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	8.8	10.6	10.9	13.1	10.9	22.5	23.3	23.7	28.4	31.2
1	17.6	18.7	18.7	17.9	12.7	23.3	25.3	26.2	31.8	33.9
2	23.0	22.9	23.9	24.3	24.2	27.2	26.7	31.7	32.6	34.4
3	25.3	25.0	25.6	26.1	28.6	28.9	30.9	32.5	33.2	34.6
4	26.3	28.8	26.9	28.6	30.4	31.5	31.7	32.7	34.7	35.1
5		30.7	30.7	30.3	30.5	31.6	32.3	32.8	35.2	35.3
6		31.6	32.1	31.1	30.4	31.6	33.7	33.3	35.3	35.3
7		33.0	32.3		31.2	31.7	34.2	33.9	35.4	
8					31.4	31.7	34.4	34.0	35.5	
9					31.4	31.8	34.5	34.0	35.5	
10					31.5	32.1	34.6	34.0	35.6	
12					32.4	32.2	34.9	34.5	35.6	
14						33.9	34.9	34.5		
16						34.3	34.9	34.6		
18						34.3	35.1	34.8		
20						34.3	35.2	34.9		
22						34.9	35.3	34.9		
24						34.9	35.3	35.2		
26						34.9	35.3	35.2		
28						34.9	35.3	35.2		
30						34.9	35.3			

APPENDIX 2D (cont.). Salinities ($^{o}/_{oo}$) in Melaleuca Inlet on 27 May 1989.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	1.5	4.0	4.9	5.3	8.4
1	19.3	19.1	14.4	16.9	15.2
2	21.1	21.2	22.9	24.2	23.5
3	21.3	22.2	26.3		25.8
4		22.5	27.3		28.8
5					31.0
6					31.9
7					32.6
8					32.7
9					32.7

APPENDIX 2E. Salinities ($^{o}/_{oo}$) at Bathurst Harbour and Bathurst Channel on 25 July 1989.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	6.4	6.9	7.2	7.7	7.3	12.3	22.5	23.9	30.2	33.2
1	12.4	14.4	16.5	7.2	9.2	17.7	25.6	25.8	30.5	33.3
2	24.2	23.9	25.2	25.1	27.1	31.3	29.4	32.2	33.0	34.3
3	28.7	30.3	29.7	31.5	32.1	31.3	31.6	33.4	33.3	34.4
4	31.6	33.1	32.8	33.1	33.1	31.4	33.0	33.7	34.4	34.5
5		33.6	33.3	33.2	33.1	32.6	33.3	34.2	34.8	34.5
6		33.8	33.4	33.4	33.2	32.8	33.7	34.5	35.5	
7		34.0	33.9		33.2	33.0	34.0	34.5	35.6	
8					33.2	33.4	34.5	34.6	35.6	
9					33.2	33.6	34.7	34.8	35.7	
10					33.2	34.0	34.7	35.1	35.7	
12					33.3	34.2	34.7	35.3		
14					33.4	34.5	35.1	35.5		
16					33.5	34.6	35.2	35.7		
18						34.8	35.4	35.7		
20						34.9	35.5	35.7		
22						34.9	35.5	35.7		
24						34.9	35.5	35.7		
26						34.9	35.5	35.7		
28						34.9	35.5	35.7		
30						34.9	35.5	35.7		

APPENDIX 2E (cont.). Salinities ($^{o}/_{oo}$) in Melaleuca Inlet on 25 July 1989.

Depth (m)	Boat Landing	Deep Landing	Mines Hut	Claytons Hut	Celery Top I.
0	9.2	8.6	7.0	7.0	7.2
1	13.4	10.5	10.7	16.5	7.5
2	22.6	24.1	25.3	26.5	27.0
3	24.9	25.1	31.5		33.1
4			32.1		33.1
5					33.1
6					33.3
7					33.4
8					33.5
9					33.6

APPENDIX 2E (cont.). Salinities ($^{o}/_{oo}$) in Old River on 25 July 1989.

Depth (m)	Mouth	First Bend	Huon Pines	Islet
0	6.3	1.3	0.1	0.0
1	12.4	14.2	13.5	18.2
2	24.2	20.0	19.4	
3	28.7	21.7	21.2	
4	31.6			

APPENDIX 3. Invertebrate species collected from artificial algal clumps placed in Bathurst Harbour and Bathurst Channel (+ indicates species presence). Species which could only be identified to genus or higher taxon are not listed.

Species	Old R. Mouth	Dixon I.	Celery Top I.	Bathurst Narrows	Sarah I.	Breaksea I.
Crustacea						
Amarinus laevis (Targioni Tozzetti)	+					
Amarinus lacustris (Chilton)		+		+		
Amaryllis macrophthalma Haswell		+	+	+	+	+
Aora ?mortoni (Haswell)						+
Aora maculata (Thomson)				+	+	
Apanthura xanthorrhoea Poore & Lew Ton					+	
Baracuma alquirta Barnard & Drummond					+	+
Cancer novaezelandiae (Jacquinot & Lucas)		+				
Caprella equilbra Say						+
Ceradocus sellickensis Sheard						+
Chlorotocella leptorhyncus Stimpson					+	
Cypsiphimedia edgari Moore						+
Gammaropsis thomsoni Stebbing					+	+
Halicarcinus ovatus Stimpson	+	+	+	+	+	+
Haplocheira barbimana (Thomson)					+	+
Haswellia emarginata (Haswell)					+	+
Hyale ?kandari Barnard					+	+
Ischyromene rubida (Baker)	+	+	+	+	+	
Lembos clematis Moore			+		+	
Lembos verrucularum Moore					+	
Leptochelia ?ignota Chilton				+	+	
Leucothoe ctenochasma Moore					+	+
Leucothoe neptunea Moore					+	
Litocheira bispinosa (Kinahan)					+	
Macrobrachium intermedium Stimpson		+	+	+	+	
Maera viridis Haswell					+	+
Mallacoota carteta Barnard					+	+
Mallacoota diemenensis (Haswell)					+	+
Melita cf. *inaeqistylis* Dana	+		+	+		
Mesanthura astelia Poore & Lew Ton					+	
Mesanthura stypandra Poore & Lew Ton						+
Microdeutopus varietensis Moore					+	+
Moolapheonoides kadee Barnard					+	+
Nannastacus inflatus Hale				+	+	+
Naxia tumida (Dana)					+	+
Pagurapseudes whiteleggei Chilton				+	+	
Palaemon serenus Heller		+	+		+	+
Paracilicaea hamata (Baker)					+	+
Paracorophium excavatum (Thomson)	+		+			
Paradexamine cf. *thadalee* Barnard	+	+	+	+	+	+
Paradexamine churinga Barnard					+	+
Paradexamine dandaloo Barnard				+		
Paradexamine frinsdorfi Sheard						+
Paradexamine moorehousei Sheard					+	
Paranthura involuta (Whitelegge)						+
Parawaldeckia yamba Barnard				+	+	+
Siriella vincenti Tattersal		+	+			

APPENDIX 3. (Cont.)

Species	Old R. Mouth	Dixon I.	Celery Top I.	Bathurst Narrows	Sarah I.	Breaksea I.
Mollusca						
Alvania fasciata (Tenison Woods)			+		+	
Alvania suprasculpta May					+	+
Amphithalamus luteofuscus (May)					+	
Austrodiaphna brazieri (Angas)				+		
Austromitra analogica (Reeve)				+	+	
Cadulus vincentianus Cotton & Godfrey						+
Calliostoma armillata (Wood)					+	
Cantharidella tiberiana (Crosse)					+	+
Cinctiuga diaphana (Verco)						+
Clanculus plebejus (Phillipi)			+	+	+	+
Cystiscus angasi (Crosse)				+	+	+
Dentimitrella cf. pulla (Gaskoin)			+	+	+	+
Dentimitrella tayloriana (Reeve)				+	+	+
Diala lauta (Adams)				+		+
Eatoniella atropurpurea (Frauenfeld)						+
Eatoniella galbinia (Laseron)					+	+
Eatoniella melanochroma (Tate)					+	+
Hedleytriphora fasciata (Tenison Woods)					+	+
Hydrobia buccinoides (Quoy & Gaimard)	+	+	+	+		
Lirinoba unilirata (Tenison Woods)					+	+
Lironoba australis (Tenison Woods)					+	+
Littorina praetermissa May						+
Macrozafra fulgida (Reeve)				+	+	+
Macrozafra lurida (Hedley)						+
Mcrozafra atkinsoni (Tenison Woods)						+
Melanella petterdi (Beddome)					+	+
Merelina cheilostoma (Tenison Woods)					+	+
Micrastrea aurea (Jonas)						+
Microdiscula charopa (Tate)					+	+
Monophorus angasi (Crosse & Fischer)						+
Notoacmaea flammea (Quoy & Gaimard)	+	+	+	+	+	
Notoacmaea petterdi (Tenison Woods)						+
Odostomia occultidens May					+	
Paraguraleus kingensis (Petterd)					+	
Pillarinella caledonica Jousseaume					+	+
Pisinna approxima (Petterd)						+
Pisinna circumlabra Ponder & Yoo					+	+
Pisinna frenchiensis (Gat. & Gab.)					+	+
Pisinna tumida (Tenison Woods)					+	+
Pseudodaphnella mayana Hedley					+	
Putilla porcellana (Tate & May)			+	+		
Rissoella imperforata Ponder & Yoo					+	
Rissoella micra (Finlay)					+	
Rissoina fausta Hedley & May					+	
Scissurona rosea Hedley						+
Specula turbonilloides (Tenison Woods)					+	+
Strombiformis lodderae Hedley					+	
Tatea rufilabris (Adams)	+	+	+	+		
Zaclys dannevigi (Hedley)					+	+
Zaclys semilaevis (Tenison Woods)						+
Zalipais inscripta (Tate)						+
Zalipais laseroni Kershaw			+			

APPENDIX 3. (Cont.)

Species	Old R. Mouth	Dixon I.	Celery Top I.	Bathurst Narrows	Sarah I.	Breaksea I.
Echinodermata						
Amphipholis squamata Delle Chiaje				+	+	+
Antedon ?loveni Bell					+	
Goniocidaris tubaria Koehler					+	+
Heliocidaris erythrogramma Valenciennes					+	+
Nectria ocellata Perrier						+
Tosia magnifica (Müller & Troschel)					+	+
Chaetognatha						
Sagitta guileri Nyan Taw			+			
Polychaeta						
Neanthes valii Kinberg	+	+	+	+	+	+
Nereis bifida					+	+
Platynereis dumerillii antipoda Hartman	+	+	+	+	+	+
Ichthyes						
Alabes parvulus (McCulloch)					+	+
Neoodax balteatus (Valenciennes)	+	+	+	+	+	+

APPENDIX 4A. Mean number of fishes collected per gillnet at different sites during October field trip.

	Old River	Melaleuca Inlet	Bathurst Harbour	Celery Top Is.	Platypus Pt	Bathurst Narrows	Channel Entrance
Number of nettings	4	4	2	4	2	4	4
Species							
Squalus acanthias	0	0	73.5	9.3	0	21.5	6.0
Mustelus antarcticus	0	0	0	2.3	0	1.8	0.3
Callorhynchus milii	0	0	0.5	1.8	0	0.3	0
Notorhynchus cepedianus	0	0	0	0	0	0	0.3
Cephaloscyllium laticeps	0	0	0	0	0	0	0.3
Pseudophycis bachus	0	0	1.0	0.8	0	1.0	0.3
Cyttus australis	0	0	0	0	0	0	0.3
Hippocampus abdominalis	0.3	0	0	0	0	0	0
Stigmatopora argus	0	0	0	0	0	0.3	0
Neosebastes scorpaenoides	0	0	0	0	0	0	0.8
Cheilidonichthys kumu	0.3	0.3	0	1.0	0	0	0
Platycephalus bassensis	0	0	0	0	0	0.3	0
Pentaceropsis recurvirostris	0	0	0	0	0	0	0.3
Nemadactylus macropterus	0	0	0	0.3	0	0	0
Notolabrus fucicola	0	0	0	0	0	0.3	0.3

APPENDIX 4B. Mean number of fishes collected per gillnet at different sites during November/December field trip.

Species	Old River	Melaleuca Inlet	Bathurst Harbour	Celery Top Is.	Platypus Pt	Bathurst Narrows	Channel Entrance
Number of nettings	4	4	4	4	3	4	4
Squalus acanthias	0	0	13.3	24.0	22.0	24.5	0.8
Mustelus antarcticus	0	0	0.3	1.0	3.3	2.5	0.8
Galeorhinus australis	0	0	0	0	0.3	0.3	0
Callorhynchus millii	0	0	0	1.5	1.7	0.8	0.3
Raja lemprieri	0	0	0	0	0.3	0	0
Raja whitleyi	0	0	0	0.3	0	0	0
Raja sp.	0	0	0.3	0	0	0	0
Pseudophycis bachus	0	0	0.3	0.3	1.0	0	0.3
Cyttus australis	0	0	0	0	0	0	0.3
Neosebastes scorpaenoides	0	0	0	0.5	0	0	1.0
Cheilidonichthys kumu	0	0	0	0.5	0.7	0	0
Platycephalus bassensis	0	0	0	0.3	0.3	0.5	0
Latridopsis forsteri	0	0	0	0	0	0.5	0
Nemadactylus macropterus	0	0	0	0.3	0	0	0
Notolabrus fucicola	0	0	0	0	0	0.3	0

APPENDIX 4C. Mean number of fishes collected per gillnet at different sites during February field trip.

	Melaleuca Inlet	Bathurst Harbour	Celery Top Is.	Platypus Pt	Bathurst Narrows	Channel Entrance
Number of nettings	4	4	4	4	4	4
Species						
Squalus acanthias	0	25.5	4.0	9.8	7.3	3.0
Mustelus antarcticus	0	0	0	0.3	0.3	0
Heterodontus portusjacksoni	0	0	0	0	0.3	0
Cephaloscyllium laticeps	0	0	0	0	0	0.3
Callorhynchus millii	0	0.3	0.5	4.8	0.3	0
Raja whitleyi	0	0	0	0	0	0.3
Raja sp.	0	0.3	0	0	0	0
Pseudophycis bachus	0	0	0	0.5	0.5	0
Stigmatopora argus	0	0	0.3	0	0	0
Neosebastes scorpaenoides	0	0	0	0.5	0.5	0.5
Cheilidonichthys kumu	0.3	0	0	0	0	0
Platycephalus bassensis	0	0	0	0.3	0	0

APPENDIX 4D. Mean number of fishes collected per gillnet at different sites during May field trip.

	Melaleuca Inlet	Bathurst Harbour	Celery Top Is.	Platypus Pt	Bathurst Narrows	Channel Entrance
Number of nettings	2	4	4	2	4	4
Species						
Notorhyncus cepedianus	0	0	0	0	0	0.3
Squalus acanthias	0	41.5	8.0	6.5	8.3	7.8
Mustelus antarcticus	0	0.5	0.3	2.5	0.3	0.3
Callorhynchus millii	0	0.3	0.8	0	0	0
Raja sp.	0	0.3	0	0	0	0
Pseudophycis bachus	0.5	0	0.3	0	0.5	0.3
Cy tus australis	0	0	0	0	0	0.3
La ridopsis forsteri	0	0	0	0	1.5	1.3

APPENDIX 4E. Mean num. er of fishes collected per gillnet at different sites during July field trip.

Species	Melaleuca Inlet	Bathurst Harbour	Celery Top Is.	Platypus Pt	Bathurst Narrows	Channel Entrance
Number of nettings	4	4	4	4	4	4
Notorhyncus cepedianus	0	0	0	0	0	0.3
Squalus acanthias	0	54.8	2.3	7.3	17.5	4.8
Mustelus antarcticus	0	0	0	0.8	1.3	0.3
Galeorhinus australis	0	0	0	0	0	0.3
Pseudophycis bachus	0.8	0.3	1.0	0.8	0.8	0.3
Pseudophycis barbatus	0	0	0	0	0	0.3
Anguilla australis	0.3	0	0	0	0	0
Cheilido ıichthys kumu	0	0	0.3	0.3	0	0
Latridopsis forsteri	0	0	0	0	0	0.3

APPENDIX 1A. Water temperatures (^{o}C) at Bathurst Harbour and Bathurst Channel on 8 October 1988.

Depth (m)	Old R. Mouth	Bathurst Harbour 1	Bathurst Harbour 2	Bathurst Harbour 3	Platypus Pt	Farrell Pt	Branson Pt	Sarah I.	Breaksea I. East	Breaksea I. West
0	9.6	9.8	10.1	10.4	10.4	10.6	11.4	11.4	11.5	12.2
1	9.8	9.8	10.1	10.4	10.4	10.6	11.4	10.9	11.5	
2	9.8	9.9	10.1	10.4	10.3	10.6	11.0	10.9	11.8	
3	9.8	10.1	10.1	10.4	10.3	10.9	10.9	12.2	12.4	
4	10.0	10.1	10.3	10.5	10.5	11.2	11.8	12.4	12.5	
5		10.2	10.4	10.5	10.8	11.7	12.0	12.4	12.6	
6		10.6	10.8	11.3	12.2	12.1	12.3	12.5	12.6	
7		11.6	11.5		12.4	12.3	12.5	12.6	12.6	
8					12.4	12.5	12.6	12.6		
9					12.4	12.6	12.6	12.6		
10					12.5	12.6	12.7	12.8		
12					12.5	12.6	12.7	12.8		
14					12.5	12.6	12.7	12.8		
16					12.5	12.6	12.7	12.8		
18						12.7	12.7			
20						12.7	12.7			
22						12.7	12.7			
24							12.7			
26							12.8			
28							12.8			
30							12.8			